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Oceania: exploring social interactions and creativity through a multi-sensory environment game application

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Abstract

The Autism Spectrum Disorder (ASD) is a developmental disorder which comprises a group a pathologies that can appear in a child's early developmental process, often limiting personal, cognitive and communicative capabilities. One of the main symptoms associated with ASD is the social struggle derived from the inability to connect with other individuals. The main reason behind this is to be found in the impairments that children with ASD often face when expressing their own emotions and when trying to recognize the ones expressed by others. Emotions, and consequentially their interpretation and expression, lay the foundation for social interaction and connection: an individual's well-being is inevitably tied to the introspection derived from the management of their own emotions, as well as the relationship that he/she might have with those of others.

In recent years, technology has proposed itself as a great medium to help with therapy directed towards all kinds of medical conditions, including ASD. Specifically, multi-sensory environments (MSE) have seen a significant increase of usage within therapeutic contexts aimed at helping children with ASD.

Starting from an analysis of the aforementioned concepts, this thesis aims to present and describe our newly developed software, Oceania, which consists of a MSE based interactive game installed within the Magic Room, a Multi-Sensory Environment developed by i3Lab (Politecnico di Milano). Oceania aims to stimulate connection among its users, by providing an interactive environment that children can explore together and use as a mean to express their creativity. Finally, with this work we also present an explorative study employed in order to investigate on the themes of social interaction and creativity, which was conducted by monitoring play-testing sessions of Oceania.

Sommario

L'autismo è un disturbo dello sviluppo che presenta disabilità nella comunicazione, nella socializzazione e mancanza di immaginazione. Uno dei principali sintomi associati all'autismo è l'impedimento sociale derivato dall'incapacità di connettersi con altri individui. La ragione principale di ciò deriva fondamentalmente dalle difficoltà che i bambini autistici affrontano nell'esprimere le proprie emozioni e nel cercare di riconoscere quelle espresse dagli altri. Le emozioni, e di conseguenza la loroinrterpretazione ed espressione, cosituiscono le fondamenta di interazioni e connessioni sociali: il benessere di ogni individuo è inevitabilmente legato all'introspezione che deriva dal saper gestire le proprie emozioni, così come dalla capacità di rapportarsi con le emozioni altrui.

Negli ultimi anni, la tecnologia si è imposta come un ottimo mezzo per facilitare l'esecuzione di terapie mirate ad aiutare vari tipi di condizioni mediche, compreso l'autismo. In particolare, gli ambienti multisensoriali hanno subito un significativo aumento del loro utilizzo in contesti terapeutici per l'assistenza di bambini non neuro-tipici.

Partendo da un'analisi dei temi sopracitati, con questa tesi presentiamo il nostro ultimo software svillupato, Oceania, che consiste in una game-application basata sulla Magic Room, un ambiente multisensoriale sviluppato da i3Lab (Politecnico di Milano). Oceania ha l'obiettivo di incentivare connessioni sociali tra i giocatori, mettendo a disposizione un ambiente interattivo che i bambini possono esplorare insieme e utilizzare con mezzo di espressione della propria creatività. Infine, in questa tesi presentiamo anche uno studio esplorativo utilizzato per indagare sui temi di "social interaction" e "creativity", condotto monitorando sessioni di play-testing di Oceania.

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Contents

1 | Introduction

The autism spectrum, also known as Autism Spectrum Disorder (ASD) or Autism Spectrum Condition (ASC), is a neuro-developmental condition characterized by difficulties in social interaction, verbal and nonverbal communication, and the presence of repetitive behavior and restricted interests. Other common symptoms include unusual responses to sensory stimuli, and an insistence on sameness or strict adherence to routine.

In recent years, there has been a significant increase in the number of individuals diagnosed with ASD, sparking much debate and speculation about the reasons behind this trend. According to the Centers for Disease Control and Prevention (CDC) [71], the prevalence of autism in the United States has increased significantly in the past two decades. In 2000, approximately one in 150 children was diagnosed with autism, whereas in 2020, the prevalence was estimated to be one in 54 children. This increase has been observed not only in the United States but also in many other countries worldwide and it has prompted the need for improvement with regards to both better understanding the causes behind ASD, as well as crafting possible solutions to tackle its associated issues [47].

ASD often encloses a multitude of atypical behaviors associated with the communication and social interaction areas; and it is referred to as a spectrum since its associated symptoms and severity can vary significantly from case to case. For this reason, considering how wide the sphere of struggles associated with ASD can be, children who are diagnosed with such condition can benefit from a significant quality of life improvement if it is treated [50].

One of the most common issues associated with ASD is the social struggle that children and teenagers alike experience as a result of their inability to properly interpret other people's emotions [88]. Furthermore, young individuals with ASD often have difficulties expressing their own emotions as well, which can lead to additional social impairments as well as a lack of introspection.

While not all individuals with ASD struggle with emotion recognition and expression, those who do can find themselves alienated or misunderstood as a result of the central role that emotions cover in our social systems. Emotions, in fact, play a crucial part in how we form and maintain relationships with others [51, 54]: experiencing positive feelings such as joy and happiness often lays the foundation for bonding and mentally connecting with other people, allowing us to feel a sense of belonging and community, which are considered to be essential for an individual's well-being.

Moreover, emotions also serve as a form of self-expression: by making our emotions explicit in social settings, we are able to communicate our inner world to others, which allows us to feel seen and heard.

For these reasons, the social impairments that are often associated with ASD can carry a significant impact on social life and could have long-term negative consequences on different domains such as peer social interaction, cognitive abilities, daily life skills, academic achievement, and mental health [90].

In recent years, treatments to this condition have found a significant helping hand in the form of the various technology advancements [94]: according to Grynszpan et al. [37], different forms of technology based intervention -including computer programs, virtual reality and robotics- has proven to have promising results with regards to helping children with ASD. The rise of new tools has opened a world of possibilities with regards to treating ASD and alleviating/defeating its associated symptoms [36]. Among other mediums, multi-sensory environments [33, 41, 62, 86] (MSE) have gained popularity as an effective therapeutic system that can be used by patients with varying disabilities. Multi-sensory environments are adaptive and smart spaces, used to control the user's experiences through sensory stimulation. The goal of a multi-sensory environment is to create a holistic, immersive experience that can be used for a variety of purposes, including therapy, education, and entertainment. They often feature equipment that can target the visual, tactile and auditory senses and, in doing so, provide an immersive experience; which usually helps to calm and relax individuals, bringing forward their positive behavior. Examples of the most common pieces of equipment featured in MSEs are projectors, music and sound systems, vibrating devices, effect wheels; but MSEs' high flexibility offers the possibility to further expand this suite based on one's own needs and goals [22]. Notably with regards to treatment of ASD related symptoms, MSEs represent a useful tool as a consequence of their high versatility [65, 82]: they can be adapted to fit user's needs and often provide tools to facilitate the work of surrounding figures, such as caregivers and family members, which can cover important roles in the lives of children with ASD [65]. Examples such as MEDIATE [65] have employed MSE based applications in order to provide environments designed specifically for non-neuro-typical user bases.

Originally, MSEs where thought to be adequate only for patients with intellectual disabilities: the first ever instance of a MSE has, in fact, been developed with the intention of helping people focus more on capitalizing on their residual sensori-motor abilities [16]. However, over the years they have evolved to suit the need of a much larger user base; MSEs can in fact be employed to assist patients in their therapy journeys, help teachers in education or even simply be sources of entertainment [63]. As a result, it is now possible to integrate a mixed user base in the activities proposed within Multi-Sensory Environments: this facilitates the integration of marginalized categories into wider social circumstances, by providing activities that can be made us of by both neuro-typical children and children with Neuro Developmental Disorders (NDD).

While the possibilities associated with MSEs in the field of neuroscience are still being explored, research on their effectiveness is still lacking to some degree, leaving the question of how multi-sensory environments can be employed to adequately complement treatment for ASD symptoms. With this thesis, our goal is to investigate the relatively under-explored aspect of using MSEs in order to foster artistic expression and creativity in children with ASD.

We developed Oceania, a MSE based software that allows both children with ASD as well as neuro-typical children to play in an immersive and stimulating environment. Oceania is run in the Magic Room, a smart space developed for children with neurodevelopmental disorder by I3Lab (Politecnico di Milano) [34]. The Magic Room is focused on providing children with NDD a pleasurable experiential space, following a learn-through-play pattern, which can help them exercise and improve various skills, ranging from physical to social ones.

Oceania provides an interactive space where children can explore the surrounding environment through body movement: an array of possible actions is made available to the users, which can move around the room and interact with the surroundings in order to achieve visual results together. The proposed activities are aimed at favouring emotional interaction and connection between children, in order to try and act as a catalyst for the solution or alleviation of the social impairments that children with ASD often face. We aim to achieve this by providing users with a tool that can foster creativity, by letting children have control over their artistic expression.

Thesis Structure

This thesis represents our attempt at both providing an overview of the context and motivation that led to the development of Oceania, as well as a description on the various processes that contributed towards said development.

The following list provides a brief description of the chapters that lie ahead:

- **2 - Research Context:** This chapter is used to provide an overview of the context in which our software has been developed, which includes a multitude of topics (MSEs, ASD, emotion recognition and interpretations), each of which is closely introduced and examined in its own section.
- **3 - State of the Art:** This chapter explores the background of the fields upon which our project has been developed. We will delve into the analysis of existing works that share common factors with our own project, as well as neighboring areas that have been investigated and can provide useful insight in the realization of tool aimed at supporting children with ASD.
- **4 - Magic Room:** In this chapter we delve into the details of the smart space in which our application takes place, the Magic Room. Here we provide a technical overview of the various components featured within said space, analyzed from both an hardware and software perspective.
- **5 - Design:** Here we describe the principles that were followed throughout the development of this software's design. Requirements and motivations behind design decisions are also explained. Finally we present the general game concept that our software revolves around.
- **6 - Implementation:** In this chapter we present the implementation decisions that were made in order to develop the software. This includes a description of the realization process behind the game through the use of the chosen game engine (Unity) as well as an in-depth explanation of the technical and hardware related components and their interaction.
- **7 - Methods:** This chapter introduces the research that was conducted through the analysis of play sessions involving Oceania. Here we provide an explanation of the study design, as well as a description of various other technical factors that played a role in the development and execution of the research.
- **8 - Results and Discussion:** In this chapter we present the results gathered from our study and we also provide a technical analysis in light of the research questions discussed in the previous chapter. Data is laid out through charts, which are then followed by a verbal discussion of the most notable findings.
- **9 - Conclusions and Future Work:** This final chapter provides the reader with both a summary of the main topics discussed throughout the paper as well as the most notable considerations that stand out from the rest of the work. The "Future

Work" section instead provides the reader with possibly inspiring directions that this project can be taken towards in future times.

2 | Research Context

2.1. Emotions - Definition and Implications

Given the large amount of subjectivity that goes into both experiencing and interpreting emotions, it can be a rather challenging task to provide an accurate and exhaustive definition of what they truly are. For this reason, over the course of the years, emotions have been defined and categorized according to a wide variety of metrics [48]. Here we present some major interpretations of the concept of emotions, through a brief overview of papers that have investigated this field. Cabanac et al. [12] provide the following definition: "an emotion is any mental experience with high intensity and high hedonicity". This definition stems from a list of assumptions that were used to derive the essence of emotions. In his book [67], Parkinson proposes a new interpretation of emotions as a phenomena that mostly results from social interactions rather than being generated by internal stimuli. According to his view, emotions are not entirely innate to humans, by they are partially developed as social constructs. Frijda [31] instead proposes the theory according to which emotions are the result of an interpretation of outcomes made by an individual: specifically, he argues that emotions arise because events can be judged either favourable or harmful to an assessing individual. In their work [42] Izard et al. dive into the analysis of the various possible interpretations of "emotion", underlying how according to their work there is no consensus in defining emotion as a unitary concept.

Emotional phenomena constitute an important aspect of an individual's daily life [93]: emotions are usually considered to be the engine that drives our social relationships [51, 54] and often take a relevant role in impacting our mental and physical health [38]. For these reasons, an individual's well being is inevitably tied to their own emotions and his/her ability to both interpret and properly express them [18]. Mayne et al. [55], explain how negative emotions are often wrongly associated to a detriment with regards to physical well-being. In their paper they propose the theory according to which emotions, including anger, fear and distress, are instead health promoting. Emotions are complex psychological and physiological responses to stimuli, typically involving subjective experiences, expressive behaviors, and physiological arousal [43]. They are often triggered by external or internal events that are perceived to be significant, and they can be experienced as both positive or negative [31]. Some common emotions include happiness, sadness, anger, fear, surprise, and disgust, but there are many others that can be experienced in different contexts and situations [51]. They can also have a profound impact on behavior, influencing decision-making, motivation, and social interactions. As a consequence, they play an important role in our daily lives [93], shaping our perceptions and experiences of the world around us.

2.2. Autism Spectrum Disorder

Over the course of the last decades, ASD diagnoses have not only increased in number across the world, (it is currently estimated that 1 out 100 children belongs to the ASD), but their average degree of intensity has also gone up significantly [47]. In fact, diagnoses nowadays tend to show harder forms of ASD compared to the averages reached in previous decades [28]. In order to understand how to properly realize support tools for children with ASD, here we delve into an analysis of the possible causes behind this disorder. To do so, we want to examine multiple works that have attempted to interpret ASD through various lenses, providing useful insight on both understanding its causes as well as suggesting possible routes to help it. Said approaches range from studies that have analyzed the behavioural differences between autistic children and other control groups [15, 87], to studies that have instead focused on the genetic differences that separate children with ASD from the rest [21, 45, 60]. Here we present a brief description of some notable studies in this field: In their work [87], Weeks et al. conduct an experiment in order to compare the behavior of autistic children with that of other retarded, non-autistic kids with the aim of finding whether those two groups present the same interpretation of other people's emotions. Results suggest that autistic children have a higher tendency to neglect people's emotions even when compared to non-autistic retarded children. In a relatively similar project [15], Castelli et al. study the differences in emotion interpretation between children with ASD and neuro-typical children, subdividing their work into two experiments (perceptual level and semantic level emotion recognition). Their results suggest that autistic children are just as capable as normal children to pass basic emotion recognition tests, but struggle with more complex stimuli that involve facial expression. Dawson et al. [21] based their experiment on electrophysiological studies of face processing in order to compare the processes behind emotion recognition by autistic children with a neuro-typical control group. Results show that children in the ASD have a tendency to employ atypical strategies for processing faces, often characterized by reduced attention to the eyes and piecemeal, as opposed to configural strategies. In "The

Genetics of Autism" [60], Muhle et al. take a deep dive in the analysis of genetic causes of autism, highlighting a correlation between the interaction among multiple genes and the development of “idiopathic” autism. However, it is still unclear which specific genes are held responsible as the cause of autism’s development.
On a general level, experimental evidence proves that autistic children have a tendency to neglect other people’s emotions, as well as their own. This was originally explained by the Mental-Blindness theory, which was developed in 1990, through the hypothesis that autistic children have an inability to attribute mental states [32]. Nowadays this theory is considered outdated by many, as new studies have shed more light on the topic [1]. As of now, multiple causing factors are thought to be the reason behind the development of autism. Among others, the impact of environmental changes over people’s physical and psychological development has been a central point of study.
Ratajczak et al. [70] show a correlation between the timing of autism’s increased spread and environmental changes, possibly proving that autism could derive form more than just genetic causes. Landrigan et al. [49] also prove how environmental factors have the possibility to influence the development of children’s brains, especially when linked to exposure in early pregnancy. Baron-Cohen et al. [5] propose a new theory in order to explain the non-social aspects of autism which aren’t covered in the previously mentioned theories. Examples of said aspects are attention to details and narrow interests. They are explained by the Empathizing-Systemizing Theory (E-S), which finds is roots in previously existing cognitive theories such as the weak central coherence theory. Rutter et al. [74] state that the concept of brain damage is too generic and can’t be used to explain the causes of autism. According to their work, language and coding defects are the most "promising" hypothesis that could explain the underlying issues behind autism.

2.3. Multi-Sensory Environments

As already mentioned in the Introduction chapter, our software has been developed on a Multi-Sensory Environment base. In order to properly understand its foundation, here we provide a detailed description of what MSEs are, as well as an analysis of the most notable neuroscience theories that have influenced its development throughout history.

2.3.1. Embodied Cognition and Sensory Integration Theories

Before diving into the definition of MSEs, it is necessary to first analyze the two major theories that have laid the foundation upon which multi-sensory environments have been developed: "Embodied Cognition Theory" and "Sensory Integration".

- **Embodied Cognition Theory:** While it is hard to point out exactly how and when this theory was developed, we can affirm that it finds its roots in the time period 1850-1900, when phenomenologists such as Edmund Husserl and Maurice Merleau-Ponty started sustaining the idea that there are aspects of human experiences (consciousness, cognition) that cannot simply be explained by a model of the mind as computation of inner symbols ([58]). According to the Embodied Cognition Theory, the many features of cognition are shaped by aspects of an organism's entire body. Specifically, this theory considers cognition to not be limited to an abstract representation of the world, but instead suggests it is strongly influenced by aspects of an agent's body beyond the brain itself ([27]). This stance challenges standard cognitive science , effectively laying down an alternative interpretation of how our mind works at an information-processing level ([78]).
- **Sensory Integration Theory:** Ayres [2, 3], who is considered to be the godfather of "Sensory Integration", defined it as "the neurological process that organizes sensation from one's own body and from the environment and makes it possible to use the body within the environment". In other words, this theory aims at explaining the process behind the reception and interpretation of information which is gathered through our senses [81]. Additionally, as a consequence of the newly found central role that senses cover according to this theory, Sensory Integration suggests that processes aimed at stimulating senses can net physical/mental gains, especially for patients with neuro-developmental disabilities [2, 39].

The two aforementioned theories, which as already anticipated have laid the foundation for multi-sensory environments, have also allowed an evolutionary interpretation of the way our cognitive system and body are perceived to link together [91].

2.3.2. MSE - Definition and Description

Multi-Sensory Environments (also called sensory rooms) are specialised spaces that contain equipment to modify the environment [86]. These environments are often used in therapeutic settings to help individuals with sensory processing difficulties, developmental disabilities, or other sensory challenges to interact with their surroundings in a more meaningful and comfortable way [86]. However, empirical evidence shows that its target user base can be expanded to all sorts of individuals [13].

Multi-sensory environments can include a variety of elements, such as lighting effects, music, aromatherapy, tactile materials, and interactive technologies, all of which work together to create a rich and engaging sensory experience. The wide range of tools that can be featured in MSEs implies that each instance can be significantly different from the others [22], however, the common factor found among all examples of MSEs is that of being an interactive smart space built within a room. Additionally, a multi sensory environment approach always relates to a medium for communication that centers around a natural process of multi sensory stimulation. Said process must be accessible, demand-free, choice-driven, empowering, meaningful, and pleasurable, based on the needs and interest of the person [22].

As Schreuder notes [76], the way we perceive our environment can largely affect the way we feel and behave. For this reason, the high flexibility associated with MSEs is the main drawing point of their employment in fields such as neuro-diversity studies. They, in fact, provide sensory stimulation that can be controlled (intensified or reduced), presented in isolation or combination, packaged for active or passive interaction, and matched to fit the perceived motivation, interests and needs of the user. And, while sensory-stimulation alone isn't sufficient to help treat a condition such as ASD, the high customization provided by MSEs can represent a powerful tool in that regard.

Other than the previously described features, MSEs are often equipped with interactive elements called "Smart Objects", which are products and assets embedded with processors, sensors, software and connectivity that allow data to be exchanged between the product and its environment. Fortino et al. [30] define Smart Objects as "real artifacts augmented with computing, communication, sensing/actuation and storing functionalities".

Over the years, smart objects have been integrated in MSEs as complementary tools that could be used to enhance the user's experience. Examples of smart objects employed in a multi-sensory environment setting include Smart Lightning, Smart Sound System and Smart Toys. Smart lights can be programmed to change colors and brightness levels, creating a dynamic and engaging environment. Similarly, smart speakers can be programmed to play different types of music or sounds, creating a calming or stimulating environment depending on the needs of the individual. Smart toys are toys that are embedded with sensors and other electronics, allowing them to respond to different stimuli. These toys can be used in multi-sensory environments to engage individuals in play and exploration. Overall, regardless of which sensory stimulation a smart object is used to enhance, it is believed that they can be beneficial to individuals with various kinds of impairments, making them a good match for MSEs in the search for positive and engaging user experiences.

3 | State of the Art

When compared to their peers, many autistic children struggle to communicate effectively; that's why finding ways to bridge the gap between verbal and nonverbal communication can be largely beneficial [85]. A common factor found among children who are struggling to communicate their feelings is the (partial) incapability to read and express emotions [15, 87]. This can cause further struggles, not only when trying to connect with other people, but also when trying to interpret one's own feelings. In recent years, the use of digital support tools for children with ASD has seen a significant increase [26] as a consequence of the many steps forward achieved in understanding how children with ASD think and process information. While the causes of autism are still unknown, improvements made in this field have allowed the development of new tools that can help special needs children improve on some of the areas where they are lacking the most: emotion recognition and social communication [26]. In the following sections, we provide a background on the research advancements made in the field of social communication, with a focus on children with ASD. Additionally, we present an overview of meaningful projects developed in this field as well as an analysis of their results.

3.1. Multi-Sensory Environments

Many studies have been conducted with the goal of directly addressing the question of how special needs children can be helped in improving their social awareness and communication skills [41, 89] through the employment of digital support tools [6, 8, 20, 44]. In this section, we want to analyze existing projects that have tried to tackle these issues through the development of MSEs based software. On a general level, it has been found that different means of sensory stimuli , ranging from visual [6, 40, 64, 68, 75], to auditory [66], and tactile [64, 66], can help children with ASD with both expressing themselves as well as better understanding others. For example, Pares et al. [64] design and developed MEDIATE, an adaptive physical environment that allows children with ASD to interact with multimodal stimuli, giving them a sense of control of the interaction. In an hexagonal space, MEDIATE combines different elements (floor surface, tune fork, screen walls, sound interface) to provide an interactive interface that children with ASD can use to have fun in a controllable and safe space. This project shows a high focus on the concept of sense of agency: children, especially those with NDD, can often have a lack of sense of control with respect to their surrounding environment. In the real world, the multi layered stimuli that we are constantly subjected to can leave children unable to understand the cause-effect relationships that regulate the environment. For this reason, MEDIATE employs a self-regulated system that provides the user with an environment that best suits their need: when novel behavior is detected, the system provides a more complex set of interactions, and in doing so boosts the richness of the environment. Quality evaluations made in collaboration with psychologists showed encouraging results in boosting dialogue skills and improving the mood of users.

While the topic of sensory stimulation with regards to ASD has seen controversial opinions throughout its history [4], empirical evidence has shown that sensory stimuli, when customized to the needs of their users, can act as a catalyst for alleviation of ASD related symptoms [73]. More specifically, smart technology can have a positive impact on the detection and management of ASD, when developed according to implications such as easiness of use, user-context depending features and an overall effort to blend with everyday life's items [79]. As a result of the focal role that flexibility and customization both take in the development of support tools for children with ASD, multi-sensory environments, which enclose all kinds of sensory stimuli, have become a pillar in the field of therapeutic approaches that can positively impact behavior and improve overall well-being [34, 46, 82, 92]. The purpose of a multi-sensory environment is, among others, to provide a calming, therapeutic atmosphere in which an individual can explore, relax, and interact with their environment in a meaningful way. Among other things, results have shown that MSEs can help autistic children improve their social skills boosting attention, speech and activity levels.
The first large scale implementation of multisensory environments in the UK took place in March 1990 at the Whittington Hall Hospital in Derbyshire [80]. In a study that had the aim of analyzing the effectiveness of such tool with regards to ASD, 15 patients with learning disabilities where monitored while utilizing the multi-sensory environment and encouraging results where found, as the majority of them expressed some form of enjoyment and improved mood after using the MSE [80]. As this original study constituted a promising start with regards to the use of MSEs in helping children with ASD, more experiments have then been conducted on the same and neighboring topics, all based upon the use of multi-sensory environments. In a study conducted over 41 autistic children [86],

Unwin et al. found encouraging results while exploring the possibility to improve autistic children's social skills by training with MSE support. Mora et al. [59] designed a full-body interaction experience called "Lands of Fog", in which a child with ASD plays together with a typically developed child, with the aim of boosting their cooperation and social interaction. In a 6 meter diameter floor projection, Lands of Fog develops an environment where children can wander around and explore, gradually uncovering the elements present in the surroundings. The aim of the activity is to capture fireflies through the use of a smart object shaped like a net and in doing so they create companions that follow the users around as the activity progresses. A notable detail is that the creatures that can be obtained were designed by children with ASD during Participatory Design Sessions. Mora et al. [59] note that this methodology provided further engagement in the users, which were more willing to participate in an activity based on something they created. Takahashi et al. [84] developed an interactive school tool called "FUTUREGYM", which is based on the use of high quality projectors and tracking cameras, that together form an interactive floor projection system. Children with ASD as well as neurotypical children can both conduct various group activities that have then been monitored and studied with the help of teachers. The use of floor projection provides a visual aid for children with ASD, who are guided through the display of patterns and targets to take part in physical activities. Ringland et al. [72] have developed "SensoryPaint", a multimodal system that allows users to paint on a large display using physical objects, body-based interactions, and interactive audio. SensoryPaint is based on an interactive painting tool which shows a superimposed reflection of the user projected onto a canvas or wall to highlight his/her actions. It also features a proximity system which gives visual feedback to the user based on how close they are to the interactive surface. Users can paint using body motions alone or with the help of rubber balls that act as paint brushes. Finally, SensoryPaint provides two different modes of interaction: the free-painting mode is used for children to freely interact with sensory stimuli, while the template mode offers users a guided experience in which they can fill pre-constructed templates with color. The impact of SensoryPaint has been evaluated through two user studies: results demonstrate that multimodal large display, using whole body interactions combined with tangible interactions and interactive audio feedback, balances children's attention between their own bodies and sensory stimuli, augments existing therapies, and promotes socialization. Gelsomini et al. [35] designed and developed Magika, a multi-sensory environment targeted at children with special education needs. Magika integrates the wall-projection of a digital world with the use of smart physical objects to create a room that enables a wide range (tactile, auditory, visual, and olfactory) of stimuli. Other examples of MSE based projects ([56, 57, 80, 86] have also successfully employed multi-sensory stimulation in support of children with

ASD, placing an emphasis on customization by modifying the environment to effectively meet the specific needs of children who don't belong to neuro-typical groups.

3.2. Other Existing Projects to Help with ASD

While the previous section contains an overview of projects that we consider to be more closely related to ours, in this section we intend to mention and briefly analyze other existing works that have been employed on neighboring fields and could still provide useful insight. The development of new tools has also improved MSEs proposed services as new devices have been integrated into multi-sensory rooms over time. For example, Virtual Reality (VR) and Augmented Reality (AR) technologies, haptics and sound are all considered key areas of development to provide more realistic, immersive and engaging experiences.

VR, which is defined as a simulated experience that employs pose tracking and 3D near-eye displays, has been employed in the neuroscience field with increasingly positive results over the years. Among other disorders (post traumatic disorders, addiction, compulsive behavior), results suggest that various struggles associated with autism can be alleviated by therapy programs based on VR [9, 23, 83]. In their work [9], Bohil et al. provide an in depth review of the latest advancements made in the world of Virtual Reality with a focus on how said progress can help benefit the neuroscience fields. Similarly, in "Virtual Reality for the Treatment of Autism" [83], Strick et al. analyze studies conducted by various universities which have proven Virtual Reality to be an effective learning aid for children with a variety of disorders including autism. Emmelkamp's work [23] is another example of a systematic analysis aimed at studying the effectiveness of VR in fields in which it is considered to be under-explored, including that of ASD treatment.

AR, an experience that combines real-world elements with computer-generated content, has also seen an uptick in recent years with regards to its employment to help autistic users. Marto et al. [53] and Berenguer et al. [7], in their respective works, both provide a systematic review of papers and studies conducted on the effectiveness of Augmented Reality on helping children and adolescences with ASD (autism spectrum disorder). Said reviews provide information for further ideas and solutions regarding to enhance Autism Spectrum Disorder patients' well-being. Escobedo et al. [25] provide an in depth look on how AR can be used to tackle the issues related to low attention span in ASD patients. In the aforementioned paper, they also describe their application Mobile Object Identification System (Mobis), which can help teachers run therapy sessions with positive results.

3.3. Design Principles for ASD support tools

Lastly, in this section we delve into the topic of design principles with regards to creating tools for children with autism spectrum disorder. Multiple papers have been published with the goal of laying down a clear map of the the most important guidelines to follow, as well as what are the challenges that need to be overcome when working on projects ultimately aimed towards autistic users. Hayes et al. [40] presented the results of a qualitative study focused on uncovering design guidelines for interactive visual supports, in which they address the many challenges inherent to current tools and practices. Other works [17, 24] instead focused on laying down design principles that can facilitate teachers in their roles of caregivers when monitoring autistic children's training sessions. Said guidelines can boost the effectiveness of training sessions, by helping teachers track records, reduce workload, and keep students "on task" [24]. In "Educating Children With Autism"[19], the National Research Council provides a comprehensive analysis of autism by examining it through the lenses of education. This work serves as both a summary of the advancements made by the research in the field of education, as well as an analysis on how adults such as family members and teachers can positively impact the education of autistic children. Campbell et al. [14], examine the impact of behavioral intervention to help autistic children through the systematic review of papers in this topic.

4 | Magic Room

The Magic Room [33] is a multi-layered smart space created by I3Lab (Politecnico di Milano) for use by children with Neurodevelopmental Disorder (NDD) and their caregivers. It has been designed with the help of NDD specialists: it supports multimodal embodied interaction and provides a wide range of sensory (vestibular, proprioceptive, and tactile) stimuli through the employment of smart objects. The Magic Room exlpoits Cyber-Physical Systems (CPSs) in order to transform a regular room into a multisensory multimodal interactive environment, providing users with an environment that can be used to train social, emotional, cognitive and motor skills. The Magic Room is based on a multilayered software and hardware platform, which controls sensors, actuators and output devices in order to both manage their communication and orchestrate their behavior. Since originally the major focus was that of users with NDD, the Magic Room also provides a system of stimuli and interactions that can be digitally controlled by caregivers, as well as customized to meet the requirements of specific children. Nowadays, the Magic Room offers game-based activities that can be found helpful (on a educational and entertainment level) by a mixed user base, including children without disabilities. Currently, two instances of Magic Rooms are installed in two different therapeutic centers.

4.1. Magic Room's Architecture

As previously mentioned, the Magic Room is a smart space composed by multiple layers (7 in total). The *Device Layer*, which includes the software of various devices, also features sensors and appliances.

This layer combines various hardware elements to create a flexible system that has been developed in order to meet the need of customization typical of a user base with disability. For this reason, the resulting system is meant to be expandable, maintainable and prone to customization. In order for the Magic Room to be installed, the lone requirement for the hosting room is to be wide (2-5m) and high (2-3m) enough for the equipment to be properly deployed.

The following list provides an overview of the physical components present in the Magic Room:

- **Projectors:** Two projectors are used to display on the frontal and floor screen
- **Sound System:** Ambient sounds are produced thanks to a Dolby 5.1 Audio System
- **Kinect:** It is an input device that detects mid-air gestures, body position, movements, and voice. This component is later going to be described in further detail as it covers a center role in the realization of our project.
- **Smart Objects:** This is an array of physical objects (mainly made up of 3D soft geometric shapes and stuffed toys) embedded with boards that integrate pressure sensors, multi-axis accelerometers, gyroscope, magnetometer, and various light and sound actuators.
- **Smart Lights:** The Magic Room also features an array of smart led-based lights that can be further subdivided into static lights and mobile, graspable lights. In both cases their Intensity and colour can be regulated.
- **Smart Appliances:** A bubble maker and aroma emitter constitute the smart appliance suit of the Magic Room. Just like smart lights, said appliances can be activated and regulated on command
- **Luminous Carpet:** Philips Luminous Carpet TM is composed of LED grids embedded in the carpet tiles, which enable the display of words and graphic patterns.
- **Tablet:** This is a component that is often handed to the caregiver who monitors the play sessions, allowing them to intervene by suspending/restarting the session, as well as impacting game activities or provide new stimuli.

4.2. Magic Room's Layer Structure

In this section we present a more detailed description of the remaining 6 layers that take part in the Magic Room's system, as well as an high level representation of their interaction (Figure 4.3). Apart from the Device Layer described in the previous section, the Magic Room features 6 additional layers:

- **Database Layer:** Also named *Physical Layer*, the Database Layer provides Magka's main structures. Its main role is to store the configuration of activities and devices, while it also maintains user and activity-related data. The database structure is based on PostgreSQL, which is a Relational Database Management System that

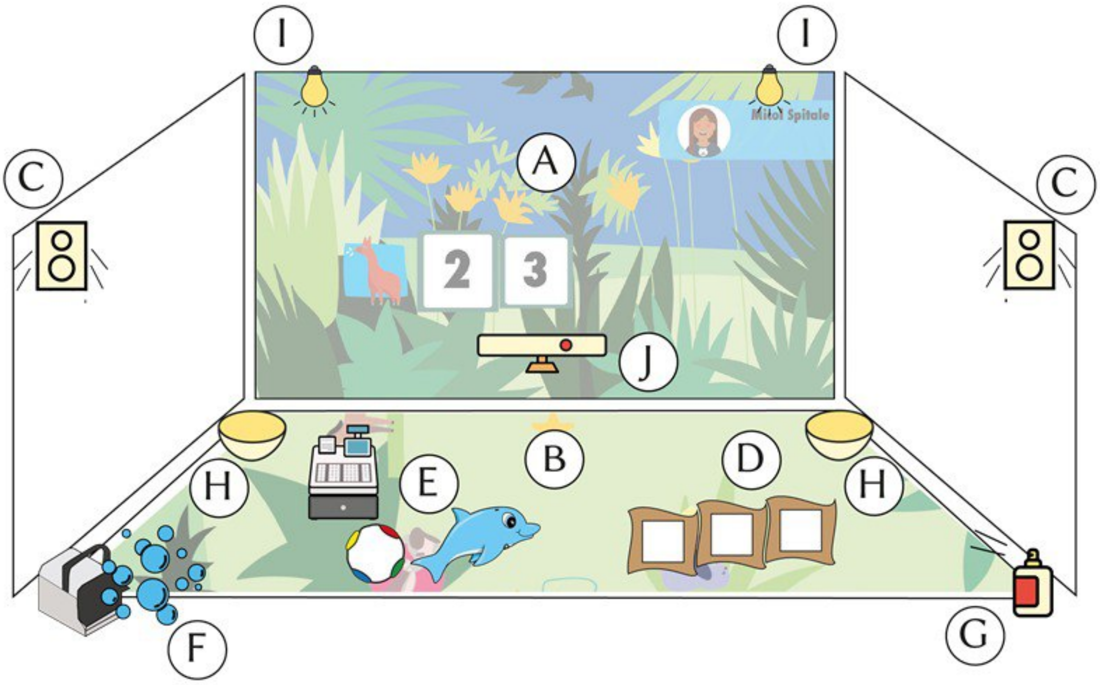


Figure 4.1: Magic Room - High Level Model

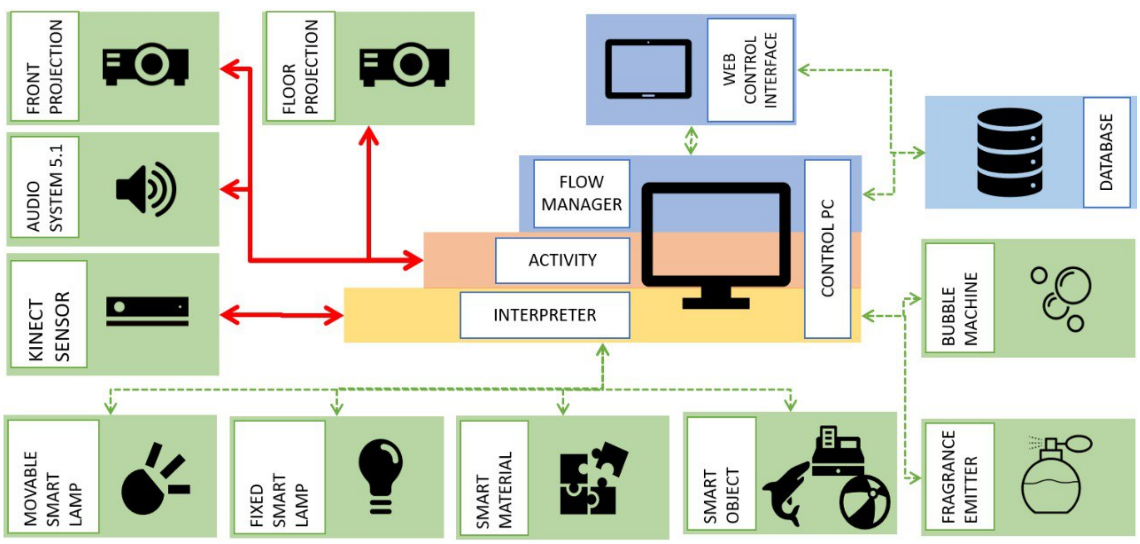


Figure 4.2: Magic Room - Components

emphasizes extensibility and SQL compliance. It features transactions with Atomicity, Consistency, Isolation, Durability (ACID) properties.

- **Middleware Layer:** The Middleware Layer, composed by elements called modules, provides software packages to access devices as well as other possible external services. A module's main role is that of creating a virtualization of hardware components, offering a calibration system used to integrate it in the Magic Room. This ensures a high level of flexibility, as the virtualization process allows for hardware changes to be executed without losing compatibility with the system. An additional role attribute to modules is that of transforming and aggregating the various devices' software APIs. The Middleware Layer is strictly related to the Device Layer as their respective elements are in close contact.

- **Activity Layer:** In this layer, the elements are called *Activities*. Each activity consists of both a logic scheme and parameters; and it has the role of adjusting the system's behavior in order to properly respond to user's actions. Activities can be divided into 3 different categories, each of which can be expanded with newly developed games over time: activities with a fixed logic, activities with graph-based logic (stories) and extra activities (dashboarding and on-boarding). Activities can be impacted by an eventual supervisor (often a caregiver or therapist), which can monitor the activity itself and manually intervene through the tablet when needed.

- **Experience Layer:** The Experience Layer, which is the top-most layer of the system, is composed by two main elements which allow for the customization, preparation and control of activities: the *Experience Manager* (EM) and the *Control Interface* (CI).

  - *Experience Manager:* This is a software application that provides users with a way to control the flow of activities. It is designed as a state based machine which defaults to an IDLE state until a log-in is detected. Upon logging in, a user prompts the Experience Manager to move to the INTRO state and then automatically reach the READY state, at which point it is going to wait for an activity to be selected. When this happens, the application fires off the selected activity, which is initially going to go through a LOADING phase and eventually reach a RUNNING state. Once the activity sends the closing command, the Experience Manager will move it to the ENDING state, which is going to be followed up by the ending of the session.

  - *Control Interface:* This interface is used to both set initial parameters as well as control in-game variables while the application is running. CI features three phases: CREATE, which is the phase were the user sets the necessary parameters for the activity to start, that are eventually loaded on screen with corresponding UI elements; PLAY, which is the phase were the user selects both the activity and the participating players; LIVE, which is the phase that covers the duration of the activity itself and allows the user to control the game flow.

- **Monitoring Layer:** This layer, which extends across the layers previously described, has the role setting up the Magic Room's components and supervising their functioning while they are being used.
- **Evaluation Layer:** The Evaluation Layer is currently being developed; its purpose is to employ machine learning algorithms in order to analyze the collected data.

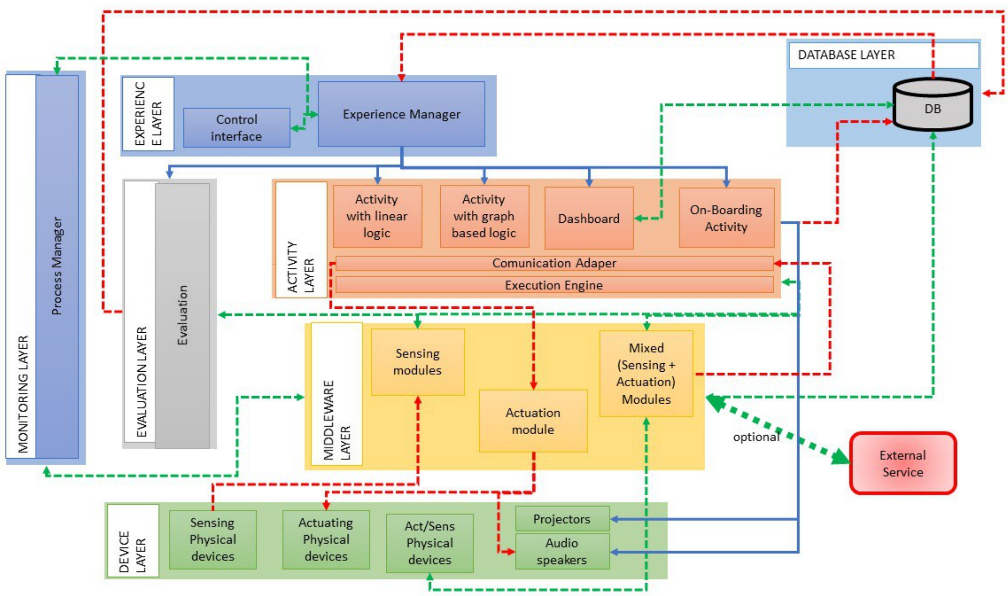


Figure 4.3: Magic Room - Layer Model

5 | Design

5.1. General Approach

The idea behind Oceania is to provide its users with an interactive environment that can be employed to enhance emotional connections between children, fostering their curiosity and creativity. This is achieved by presenting an interactive environment filled with elements that appear as visually engaging: through a process of exploration and discovery, the user is incentivized to learn what results can be yielded by interacting with the surroundings. Additionally, as a result of their experiences, players can apply the newly learnt knowledge to use in-game actions in order to create visual pieces of art together. Therefore, the experience flow that we envisioned can be summarized by the 3 following steps:

- **Exploration:** The user, who is initially oblivious to the mechanics that the surrounding environment is regulated by, can interact with in-game elements in order to learn about the results associated with each game action.
- **Creation:** Once the user learns about the tools offered by the system, he/she could choose to employ them in order to create pieces of visually stimulating pieces of art. This process incentivizes cooperation between multiple players, as the final displayed art is itself a combination of the game actions taken by each child
- **Emotion Connection:** Upon generating visual stimuli, users are expected to be influenced by them at an emotional level. We strive to analyze the emotional behavior that various users have as a result of said stimuli in order to interpret whether they had an impact on social connection.

5.2. Goals, Requirements and Constraints

In order to lay down the appropriate foundation for the design of our project, we started by listing out the major objectives that we were trying to achieve with it. The following figure summarizes all the goals that were identified, as well as their relationship with their respective requirements and constraints:

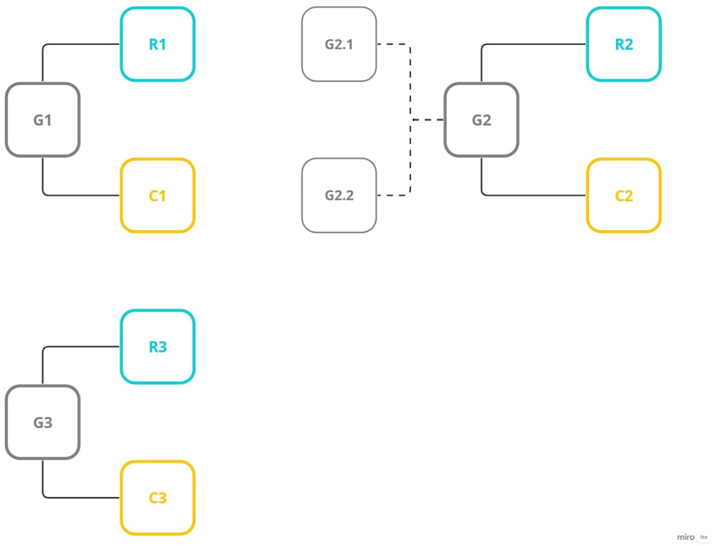


Figure 5.1: Goal, Requirements and Constraints

Here we present a list of objectives, each of which is going to be accompanied by a description of how it was derived. We'll refer to each objective as a goal (marked with G):

- **G1:** The software must run on a Multi-Sensory Room.
- **G2:** The software must be able to stimulate participants emotions. Given how this project is focused on understanding ASD children's emotions, it is necessary for it to involve a stimulation that can bring said emotions to the surface.
  - **G2.1:** The system should be intuitive and easy to use. As a result of our target user's choice, the software needs to provide an experience that isn't overwhelming or too hard to comprehend.
  - **G2.2:** The user must have a sense of agency. A player must be able to actively interact with the environment, as opposed to passively being stimulated.
- **G3:** The software must allow the study of participants' emotions. This is the ultimate goal of our project: specifically, we are trying to study how ASD children react to the interaction with our software, compared to neuro-typical participants.

After having set the goals of our project, we went on to derive and analyze the constraints and requirements that arise as a result of our chosen objectives. Here's a list of the derived requirements (marked with R) and constraints (marked with C):

- **R1** - (G1): The experience must be based on the sensory stimulation associated with MSR.
- **C1** - (G1): The software must be developed through the use of commonly accessible technology that can be integrated into a Multi-Sensory Room (Kinect, Vr, etc...)
- **R2** - (G2): The input system through which the user interacts with the environment must be intuitive and easy to use.
- **C2** - (G2): The multi-sensory room must include one or more tools through which the user can interact with the generated environment
- **R3** - (G3): The system must set the correct conditions needed to identify a user's emotion throughout the play session.
- **C3** - (G3): The software must include an emotion tracking system. In order for a proper study to take place we need a way to gather data from the play sessions, which then going to be analyzed and discussed.

5.3. Design Guidelines

As described in previous chapters, we were driven by the idea of a game with the intention of helping children with ASD socialize with their peers, as well as analyze the impact that said game was going to have on the struggles associated with such condition. Considering how the target user base for our game is made up entirely by young subjects, we decided to pivot the concept of the game towards an easy to use and intuitive tool. It is worth mentioning that designing this software has been an ongoing process, which has led to the addition of new features and minor reworks, both during the development stage and during the testing stage.

We have already discussed how multi-sensory stimulation is one of the key factors that distinguishes MSEs from other kinds of tools, and this aspect plays a central role in our project. Additionally, a key concept that we wanted to be featured is that of user's agency: other examples of existing MSE based software have found encouraging results in handing meaningful control over the environment to the users [64]. According to Fornes [29], individuals with partially invalidating disabilities often have limited opportunity to exert control over the surrounding environment. As a result, they can feel helpless, lose confidence and become withdrawn and apathetic. For this reason, we believe that the flexibility associated with being able to control one's own actions when playing a game can lead the user towards a more "natural" mind state, as opposed to just being passively stimulated by sensory feedback.

Considering all the goals and constraints that have already been discussed, the game had to be structured in a way that could encourage interactions between users, without creating a competitive environment. Stimulating competition among players would, in fact, carry the associated risk of putting them under pressure; our software's goal is instead that of providing children with a pleasant and relaxing experience, fostering creativity and curiosity. For this reason, we decided to center the user experience around taking actions that would not negatively interfere with other users, but that could instead be used to cooperate with others, in order to create appealing results together.

Additionally, we needed a game that could focus extensively on the user's experience and, more specifically, on the emotions that users go through while playing. For this reason, users' emotions ended up being central in our design, as they represent not only one of the main focus points of our project, but also the basic means of connection with other participants.

5.4. Game Concept

One of the main strengths associated with MSEs is the possibility of creating immersive experiences through sensory stimulation, which can include many practices, all aimed at activating one or more of the subject's senses. The wide range of options associated with MSEs granted us the possibility of freely choosing in which direction to take the core elements of the game and, on a more general note, which sensory based activities to include in the game. We decided to center the experience around the stimulation of user's sense through the employment of auditory and, more importantly, visual feedback. In search for an element that could act as catalyst for visual stimulation, as well as a link with the concept of emotions, we found a significant turning point in the employment of colors. As Pope et al. note [69], people tend to develop color-emotion associations from infancy, which often remain throughout life in the form of automatic emotional responses. Colors not only carry an almost innate association with emotions, but can often be means of stimulation within our everyday environment: children's mood can be impacted, both positively and negatively, by the visualization of colors [10].

After these considerations, the concept of colors ended up retaining a major role in designing the user experience: we came to the realization that the display of colors could be an impactful way to visually stimulate users. We also saw colors as a natural way to represent users' emotions, which led to the attribution of two major roles to colors: *emotion tracking* and *visual stimulation*. Said roles created the opportunity for a recursive experience: colors are used to track users' emotions, but also impact the visuals that players are exposed to and, in doing so, have an influence on users' emotions and experience.

So, considering the newly found central role that colors took in our project, we ended on the following general concept: a game where the users can interact with the environment and react to what they experience. In doing so, they impact the environment itself, potentially creating amusing results when combining efforts with other players.

5.4.1. Setting and Themes

Starting from the foundation laid in the previous section, we now describe how the game has been envisioned from a setting/theme point of view. While the choice of a theme for a game can be largely subjective, we still tried to derive the environment in which the game takes place from the goals set for the user's experience that we had in mind.

We wanted said experience to be calming and immersive, but also capable of offering opportunities to explore and stimulate curiosity. Intuitively, it felt like relaxation and exploration could be joint together in an environment based around water, which is ultimately the choice that was opted for.

We felt like the element of water could supply us with the characteristics that were wanted for our game setting: so we ended up designing an underwater space, with the idea of complementing it with calming visual and auditory pieces, such us coral wildlife and background music. The fact that the user is figuratively immersed in water gives us the opportunity to design an environment where the surroundings are just as relevant as what is displayed in the front screen, giving players more incentive to look around.

For this reason, we settled on using both the frontal and the bottom screen of the Magic Room, with the idea of representing the underwater environment from the point of view of someone who is cruising on the seabed of the ocean and looking upwards to see what lays in front of them.

- The **Floor Screen** has been utilized to represent the sand seabed on top of which users walk in order to explore the environment. Additionally, this screen also features the display of Starfishes, which are one of the core elements of the game that are going to be described in depth in the following sections.
- The **Front Screen** has instead been used to complement the environment with a focus on providing a sense of realistic depth in conjunction with what is displayed on the floor. For this reason, it displays the virtual horizon of the scene, as well as the remaining elements of the game that are not featured on the floor screen.

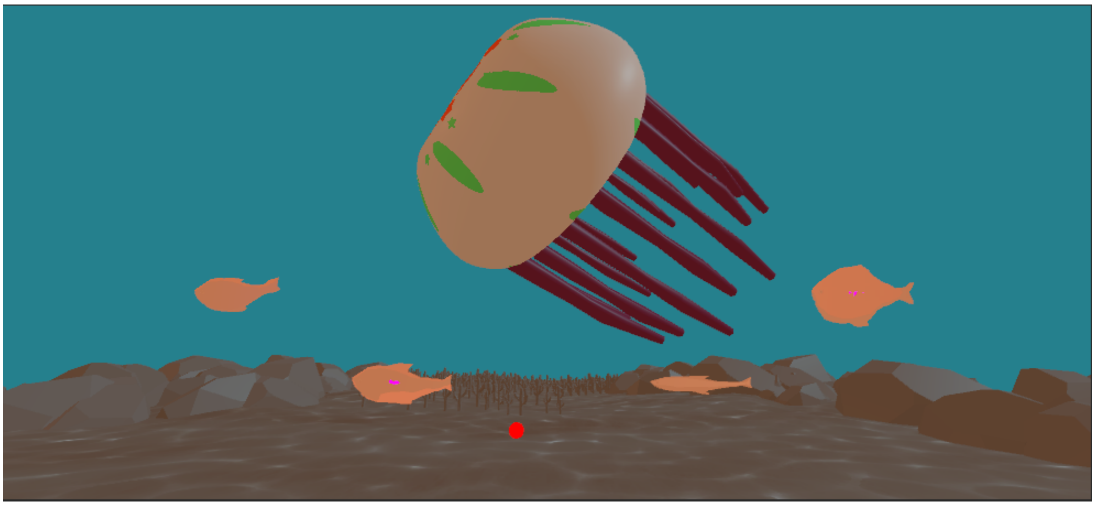


Figure 5.2: Render of frontal screen elements

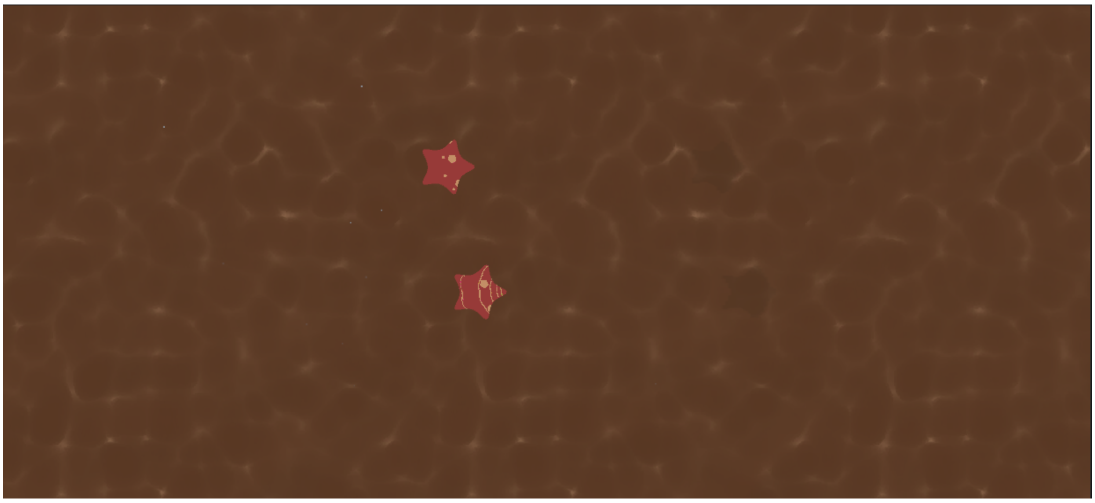


Figure 5.3: Render of floor screen elements

5.4.2. Core Game Elements

Once the setting had been decided, we were left with the task of choosing which elements would be filling the environment. Our designer proposed a way to tie all the pieces together by using a floating jellyfish as the item that would represent the emotions of the users. Having one single entity that could bring together the experiences of multiple users was a necessary way to ensure connection and cooperation between players. The jellyfish idea struck us as appropriate for this role as it would fit really well with the already established underwater theme; additionally we felt like the floating motion that jellyfishes make when moving around seemed like a good way to recall the relaxing atmosphere of the setting. So the developed solution took the following form: a moving jellyfish floats around on the front screen and connects the user by representing their emotions. The representation of said emotions comes in the way of changing the appearance (textures and colors) of the jellyfish, based on how the players are feeling (color) and which texture is currently associated to them (texture shape). In order to clearly display the connection that each user has with the Jellyfish, a chain of floating bubbles moves from the player's feet to the Jellyfish itself, representing a visual connection between the two entities. As a result, each player has got his/her own associated flow of bubbles, which is made by bubbles of the same color of the emotion associated with the user at a given time.

As already described, colors cover a very important role in the user experience, they are both used to track player's emotions as well as complement the surrounding environment in order to visually stimulate the users. The tracking system is based on the mapping of basic emotions into different colors, so that users can be assigned a specific emotion-color pair at any given time during the playing session. In order to define the mind state of a user, the system has been broken down to 8 basic emotions (Happy, Sad, Surprised, Interested, Angry, Afraid, Disgusted, Neutral) and for each of those, a color to be paired with it has been defined. The "Neutral" emotion represents the default mind state that users are associated with when the game starts and cannot be regained when a new emotion is assigned to the player. On the other hand, the other emotions are all meant to represent a specific feeling that the user is going through when playing: the aim is to assign the emotion-color pairing that best represents what the user is feeling at a given time. For this reason, there is no constraint to how the color of a player changes: a user can in fact be assigned multiple emotions throughout the session, but it always limited to one at a time. This labelling system offers a way to keep track of the user's state of mind throughout the play session, letting us know how different users react to the various sensory stimuli. One of the underlying goals with the implementation of such emotion-color system is to also identify the periods during the game where two or more users share the same emotion, which would be a possible indicator of connection between them. The following schema (Figure 5.4) presents all 7 emotions-color pairings that are used to classify the user's mind state:

Figure 5.4: Emotion-Color mapping schema

In order for this system to be effective, the labelling needs to be accurate, meaning that colors need to actually represent the emotion that best summarizes what the user is feeling at a given time. Going by one of the requirements previously stated (the fact that the playing sessions are monitored by a caregiver), we decided it would be an adequate solution to give the responsibility of assigning labels to the caregiver themselves, instead of implementing an automated system. While this puts the onus of making the software function on a single person, we felt that using an automated system instead would have yielded much less accurate labels, resulting in a not trusted method. In order for the caregiver to have the highest accuracy possible while attributing emotions to the user, it is advisable and expected that he/she communicates constantly with the players throughout the session.

We discussed the central role that colors take in the game, but there's still one missing piece that is yet to be described: the way they are represented. Each user is associated with a color at any given time during the play session, but they can be displayed on top of the jellyfish in various shapes, which we'll call "Patterns" (Figures 5.5a,5.5b). A Pattern represents the shape associated to a player, which is used to display their emotion on the front screen. Each user can have only one pattern at a time, which is painted on top of the jellyfish, which in turn combines patterns from all players into a unified result. Despite the fact that patterns are independent from each other and each player has their own, 2 patterns from different players can overlap when pictured on top of the jellyfish. This leads to a final result that depends on the interaction between the patterns of multiple users: the final figure pictured on the jellyfish is, in fact, a combination of the patterns taken from each user. Unlike colors, which are automatically assigned to the users based on their current emotions, patterns can be chosen by the users themselves, by interacting with the environment. A player can in fact change their pattern multiple times throughout the game, but the pattern is always going to be filled with the current color associated with its user.

(a) Example of a single pattern

(b) Example of multiple overlapping patterns, combining into a final geometric result

It is also worthy of mention that the possible patterns associated to each starfish are all geometric sequences that are meant to complement each other when put together on the jellyfish texture. The combination of multiple patterns, each belonging to a different player, is going to result in a final geometric figure pictured on top of the jellyfish. Given how this expected result relies on multiple players in order to create interesting combinations, we decided to merge together multiple patterns inside each starfish when the game features only two players. So, when there are only two players, each starfish is going to be carrying a random combination of two patterns in order to still have a total of 4 patterns combined when both players feature their own on the jellyfish.

5.4.3. Jellyfish

The *Jellyfish* is arguably one of the most important game elements of Oceania; it has already been introduced in previous sections, but here we aim to provide a comprehensive description of all its game mechanics related features. Firstly, as already discussed, it is the element that visually connects users: each player has a ray of colored bubbles that sprays from his/her feet towards the jellyfish itself. By receiving bubbles from all players, the jellyfish acts as a visual link between them. Additionally, it is the game element upon which all "player owned" patterns are pictured: every possible action taken by a user reflects on the jellyfish by changing part of its texture (color, scale, rotation).

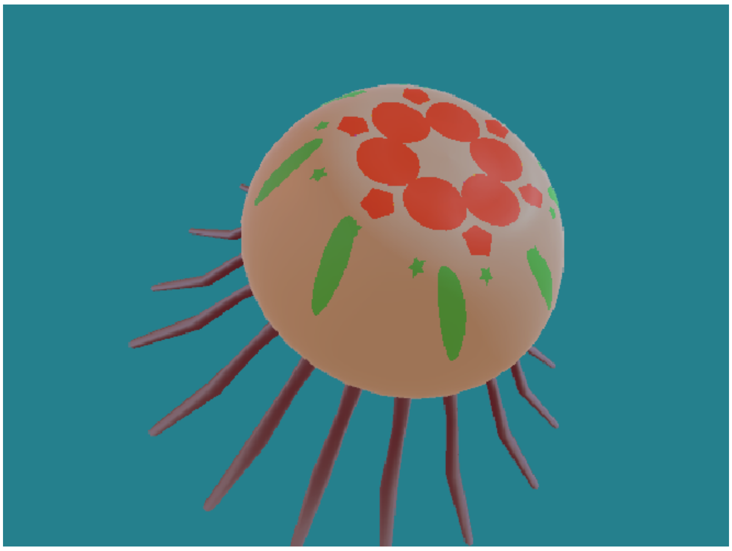


Figure 5.5: Jellyfish

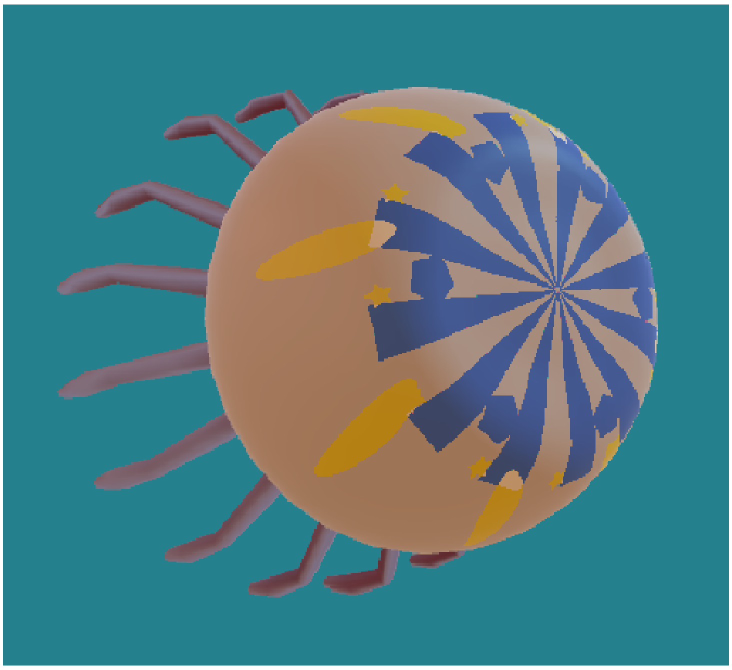


Figure 5.6: Jellyfish

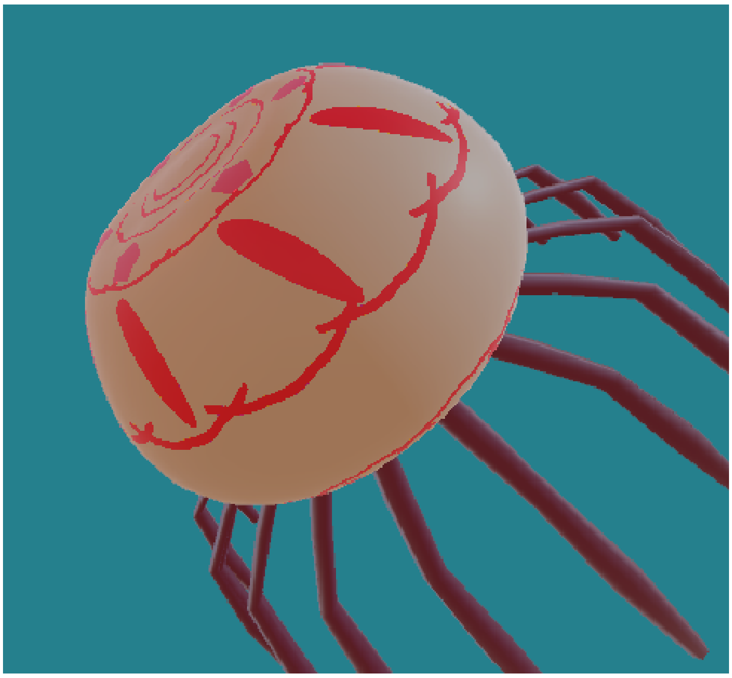


Figure 5.7: Jellyfish

The jellyfish is displayed in the frontal screen and moves around in front of the users following a semi-random motion: its rotation and direction are randomly selected, but it is confined within a sphere of space, which keeps it always visible in the frontal screen.

5.4.4. Interactive Game Elements

In this subsection we will discuss the topic of interactive items, which are the elements of the games that the users can interact with in order to change characteristics of their associated pattern(s). Said items can be used by the players to change the shape and rotation of their patterns, as well as acquire a new pattern altogether. These elements provide the users with a gateway to exploration: the interactability aspect of said elements poses the user with the question of which would be the result of interacting with them. Additionally, upon discovering which consequences are associated to interacting with the surrounding environment, players are incentivized to explore the possibilities that said interaction could lead them to. For these reasons, these items can foster players' creativity and curiosity.

We can divide the interactive items into 2 different macro-categories: *Starfishes*, *Power-Ups*.

5.4.5. Starfishes

A *Starfish* (Figure 5.8) is a floating item that can be captured by the user in order to acquire a new pattern.

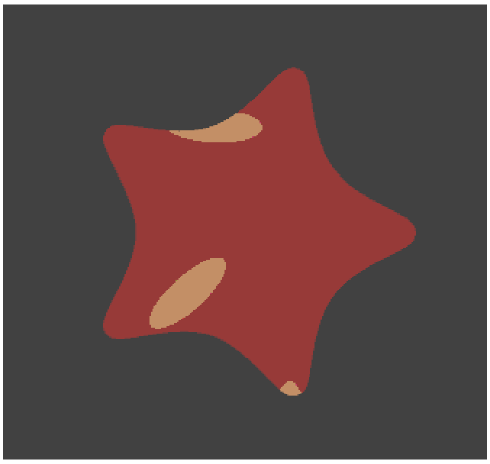


Figure 5.8: Starfish

Each starfish moves around independently in the floor screen and carries a different pattern. Upon being captured by a user, the starfish grants its pattern to the player, which will result in immediately changing his/her current pattern displayed on top of the jellyfish. Each user starts the game without an associated pattern, which implies that the first starfish to be captured is simply going to grant a starting pattern. From there on, if a new starfish is captured, the old one disappears and the new starfish (with a different associated pattern) takes its place. In order for a user to capture a starfish, all they have to do is step on it and stand still for a long enough time. As a visual feedback, the starfish becomes increasingly more luminous as it is being captured. The catching process is completed when the player has remained on top of a starfish for a certain amount of seconds, at which point a little particle animation takes place in order to notify the user of their successful capture. Upon being captured, a starfish is going to start following the user around, in order to show that it "belongs" to its new user. However, each player retains an "inner circle" that determines how close its starfish is going to get when following the user around. This means that whenever the user makes a movement, the starfish is going to follow through in that direction and is also going to adjust its speed to the one of the user, until it reaches the player's inner circle, at which point it's going to stop. This is done in order to avoid that the starfish gets too close to the user's feet: considering how the act of capturing a new starfish involves standing directly on top of it, it would be too distracting to have the currently owned starfish reach a spot that's directly below the user's feet. Finally, the starfish is going to align its color to the user's emotion and is going to change accordingly if the player himself/herself changes emotion throughout the game session.

Initially starfishes where meant to stay still in their spawning spot, which was determined randomly within the bottom screen space. With the help of our designer, we decided to change this feature and make the starfishes moving items instead. Currently they spawn out of screen sight and move towards the center of the screen in a straight line, with the addition of a noise component that slightly changes their angle of movement (this is done in order to avoid for every starfish to go through the exact center point of the screen, which would result in a player being potentially able to capture every starfish by standing still in the middle of the room). Upon reaching the other end of the screen, if a starfish isn't captured it exits out of screen sight and disappears. In order to always keep starfishes available for the player to interact with during the game, a new one is spawned when an old starfish is either captured or exits screen sight. We believe this adds more variety to the pattern system, given how players could choose to disregard starfishes with patterns that they aren't interested in and get new ones to interact with as a result of that.

5.4.6. Power-Ups

Power-Ups are also interactive items, but unlike Starfishes, they don't move around and instead stand still on the front screen, always available to be interacted with. In order to interact with a power-up, a user needs to raise his/her right hand and maintain it in front of the power-up until it's captured. Similarly to what happens with starfishes, power-ups provide the user with a visual feedback while they're being captured, in order to notify the player about the progress made during the capturing process. The visual feedback system in this case consists of an outward circle that surrounds the power-up and which is initially invisible. When a power-up begins being captured by a player, its circle starts becoming visible and gets progressively more filled with color until it reaches the point at which it is fully visible. Upon completion of the capturing process, power-ups grant their associated effects to the user's pattern. Power-ups' effects are persistent, which means that users are going to maintain the effects of the power-ups they captured unless they decide to capture opposing power-ups that revert said effects. There is a total of 4 power-ups that players can interact with in order to modify their own pattern, which could be split into separate pairs: each pair of power-ups contains 2 opposite effects. Here are the 2 categories of power-ups:

- *Size Power-Ups:* the two power-ups that belong to this category grant the user the possibility to change the size of his/her pattern displayed on top of the Jellyfish. One of these two power-ups enlarges the scale of the user's pattern, while the other reduces it. Both power-ups affect the scale of the pattern to the same degree, except that they work in opposite ways.
- *Rotation Power-Ups:* the other two power-ups can instead be used to rotate one's own pattern, providing a clockwise and counter-clockwise rotation respectively. Similarly to the previous pair, these two power-ups also affect the rotation of the player's pattern to the same degree. Effectively this implies that users can choose to collect opposing power-ups in order to revert the effect granted by previously collected power-ups.

The following table provides a more in-depth description of all 4 power-ups available, which are shown together in Figure 5.9:

ID	NAME	EFFECT	POSITION
0	Up-Scale Power-Up	Retrieves the current scale of the user's pattern and multiplies it by a constant $c>1$	left-most position
1	Down-Scale Power-Up	Retrieves the current scale of the user's pattern and multiplies it by a constant $c<1$	center-left position
2	Clockwise Power-Up	Retrieves the current rotation of the user's pattern and adds to it a constant c amount of degrees	center-right position
3	Counter Clockwise Power-Up	Retrieves the current rotation of the user's pattern and subtracts to it a constant c amount of degrees	right-most position

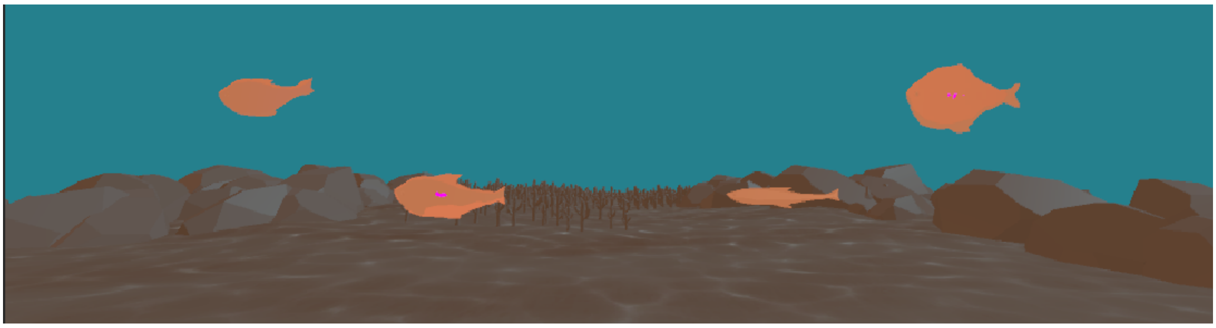
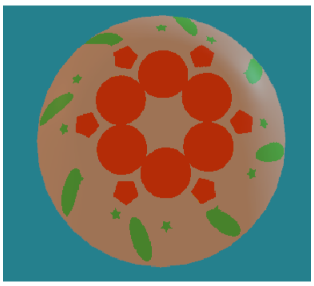
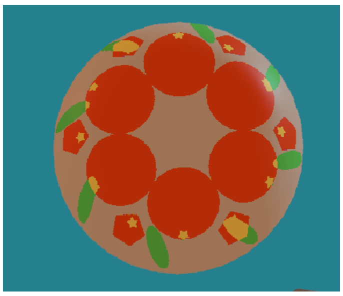


Figure 5.9: Starfish

In the following two Figures (5.10a, 5.10b), we can observe an example of the Up-Scale Power-Up's effect on a player's pattern that is pictured on top of the jellyfish's cup:



(a)



(b)

Figure 5.10: Jellyfish's cup before (left) and after (right) a power-up's effect activation

6 | Implementation

6.1. Technical Limitations

Although there is no upper or lower limit to the amount of players that can join the game at the same time, this software is been thought with a target player base of 2-4 members in mind. While it is technically possible for a single player to play by themselves, it's equally true that the scope of this project focuses mainly on how multiple individuals interact with each other throughout the session. On the other hand, having too high of a number of users play a the same time wouldn't be optimal because of technical limitations imposed by the Kinect and the Magic Room. Firstly, the Kinect can only track up to 6 different bodies at the same time; additionally the Snoezelen room in which our studies were conducted doesn't offer enough space to reach larger scales in terms of how many players can participate simultaneously.

Given how the game has been structured to be a way to explore and express oneself, there is not an end goal that users have to look forward to in order to complete or finish the playing session. For this reason, the session is regulated by a timer that determines its duration. The timer is set initially by the caregiver, but can be extended on demand once the session starts.

6.2. Hardware Components

In the following section we provide an in-depth look at the hardware components that our software utilizes. Some of these tools have already been partially described in previous sections, but now we analyze them from a technical standpoint. Here are the various hardware components that the system is based on:

- **Magic Room:** The Magic Room, which is already been extensively described, features multiple equipment pieces that we are yet to touch on individually. Each of these tools has the general purpose of enhancing the sensory experience of the user, as they provide stimulation for one or more senses:

  - *Smart Lights:* There are four independent lights that can either be controlled remotely or automated via code. These lights can change color and direction on command. In our case, we automated their management via code, synchronizing all four lights to the same colors, which are changing over time throughout the game.
  - *Sound System:* The Magic Room features multiple speakers which are used to reproduce sound across the room. Audio inputs are utilized in our game to both give auditory feedback as well as setting the atmosphere for the game. There is a constant background music being played throughout the game session, which helps with setting the relaxing mood of the experience. On the other hand, all the interactive items that have already been mentioned in the previous sections give some sort of sound feedback in order to notify the user when they've successfully accomplished a game action.
  - *Screen Projectors:* There are two screen projectors that are used to display the content of the game. One is projecting on the floor, while the other projects on the front wall. These two components are used to give a sense of immersion to the room.

- **Kinect:** This piece was also introduced in previous paragraphs, but here we give an in-depth description of how it functions and how it has been employed in our game. The kinect is a motion sensing device, usually equipped with cameras, projectors and detectors that are used to map depth in order to track and reproduce real time body motion. Its movement mapping feature can be used on multiple bodies at the same time, allowing players to join the game through the same device. Each body sensed by the kinect is mapped to an in-game skeleton that accurately reproduces the player's movements. This allows us to keep track of various points of the user's body: in our game we follow the player's center of gravity to keep track of his/her virtual position inside the game world as well as the player's hand, which is the part of the body that can be used to interact with power-ups. In addition to the features just described, the kinect is often equipped with a microphone array that can be used for voice and speech recognition, often employed to give the player control over the game through his/her voice. In our case, however, this feature isn't employed as all the game actions available to a user can be executed through body motion.
- **Tablet:** This is the tool that is handed, before the session begins, to the caregiver who is monitoring the play session. It features a simple application that enables the caregiver with the functionalities that he/she has to use during the game. First

and foremost, the caregiver needs to be able to set the emotion-color of a player at any point during the session. For this reason, the application features a side panel with player icons that can be clicked at any time. Upon clicking an icon, the application displays a page with various colored buttons, each of which is associated with a color-emotion pairing. The caregiver can then press one of the buttons in order to assign its associated emotion to the currently selected player. We've already mentioned the fail case of the kinect, which can lead to the miss-association of two or more skeletons, that's why we felt it was going to be necessary to have an emergency system that could restore the correct associations. For this reason, the application also offers a way to swap skeleton-player pairings which can be used on command by the caregiver. In order to do so, the caregiver shall first click on a player icon and then on the newly appeared swap button. At this point the application presents multiple player-buttons that can be clicked to swap the skeleton of the currently selected player, with the one associated with the button. Lastly, we've mentioned how the total game time can be adjusted throughout the session: the application provides a way to add time by clicking the relevant button, which is always visible on the lower bar. (-insert tablet images-)

6.3. Player-Kinect Binding

As previously mentioned, the Kinect offers a way to track players' movement when they enter screen sight. Upon being detected by the Kinect, a player is immediately associated with an in-game skeleton that tracks the user's movements and reproduces them within the game world. However convenient this is, we still need a way to associate each player with their correct in-game ID, which is independent from the skeleton that was randomly attributed to them by the Kinect upon entering screen sight. This is necessary in order to be able to properly apply the emotion-color attribution imparted by the tablet to the correct player, which is again represented by an in-game ID. The following figure (6.1) provides a summary for the problem in question:

In order to have a clear mapping of the skeletons with respect to the players and their in-game IDs, this software features an initial preparation process that the users have to go through before being able to start playing. Said process involves the use of visual instructions that the players have to follow in order to match their skeleton to their correct player ID. The instructions are presented as lines of text in the front screen, while on the floor screen there are as many circles as the total number of players. Each circle has a distinct color, which matches the color of one of the bracelets that have been distributed

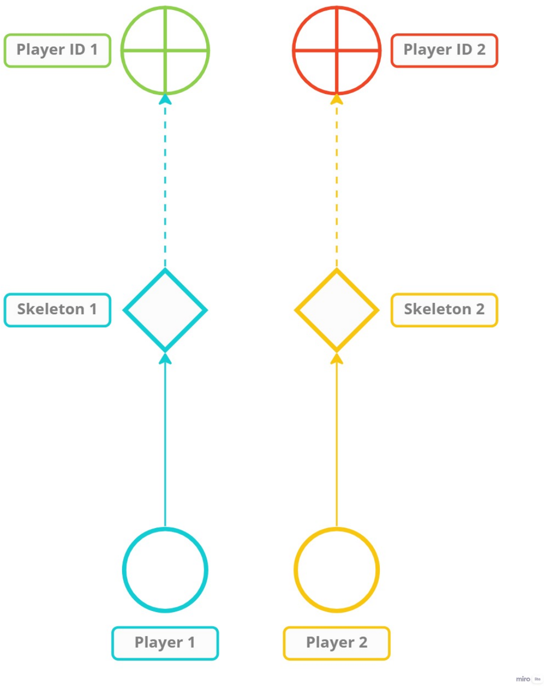


Figure 6.1: Continuous Line represents an automatic association, Intermittent Line represents the desired association

to players prior to starting this process. At this point, each player is guided through the lines of text to position themselves on top of the circle that matches their bracelet. Upon standing enough time on top of a circle, a player is going to successfully match their skeleton with the player ID associated with that circle. All this process needs in order to be completed is for all players to match themselves with the correct circle, at which point the skeleton-player mapping would be finished and the game would be ready to start. Additionally, we decided to add a small extra step to this process in order to demonstrate to the players how they can interact with power-ups, before the game begins. Upon reaching the state in which all players have successfully matched with a skeleton, a new series of circles is spawned in the front screen and the text guidelines are updated. At this point players are spurred on to hold their hand in front of their respective circle. Upon doing so, the circle, originally grey colored, is going to start filling up until it is "captured". This step concludes when all players have captured the circle they have in front and it serves as a mini tutorial to show them how they can interact with power-ups. When this last step is completed the game is ready to start.

6.3.1. Binding Loss

It is possible that during the playing session the Kinect loses track of one or more players. When this happens, skeletons can't keep following the real life movements of their associated users until said users get back to being tracked by the Kinect. In this case, the skeleton is put in a temporary state of standby, in which its movements are inhibited and it is relocated out of screen sight. However, a rather subtle issue could arise in the case of a player that momentarily exits the Kinect's view and then comes back: the Kinect in this scenario could associate the user with a new skeleton as it is most likely going to be perceived as a completely new player, disregarding the previous association that it had with the old skeleton. In order for us to be able to keep the association between the actual user and his/her original in-game player ID reference, it is necessary to once again go through the same binding process that was previously described. For this reason, whenever a player is lost track of during the playing session, a new binding circle is spawned on the side of the floor screen. Similarly to what happens in the preparation scene, this temporary binding circle awaits for a player to stand on top of it in order to re-establish an association. This whole process happens automatically and involves only the player(s) who's lost connection with his/her own skeleton, allowing other users to keep playing without having to pause the whole group's experience. It is also worth noting that players with an already active binding could not accidentally step on the newly formed binding circle (and mess up the association process as a result) as the circle itself checks for the player to not have any existing associations before committing to the binding.

6.4. Game Architecture

In this section we present and describe the overall implementation of our game from an high level modeling perspective; also, the major components of the game architecture are going to be explored in further detail. The presented model is aimed at explaining the underlying structure that the game system is based analyzed from the perspective of the components that populate the game scenes. The following figure represents the high level view of the UML model:

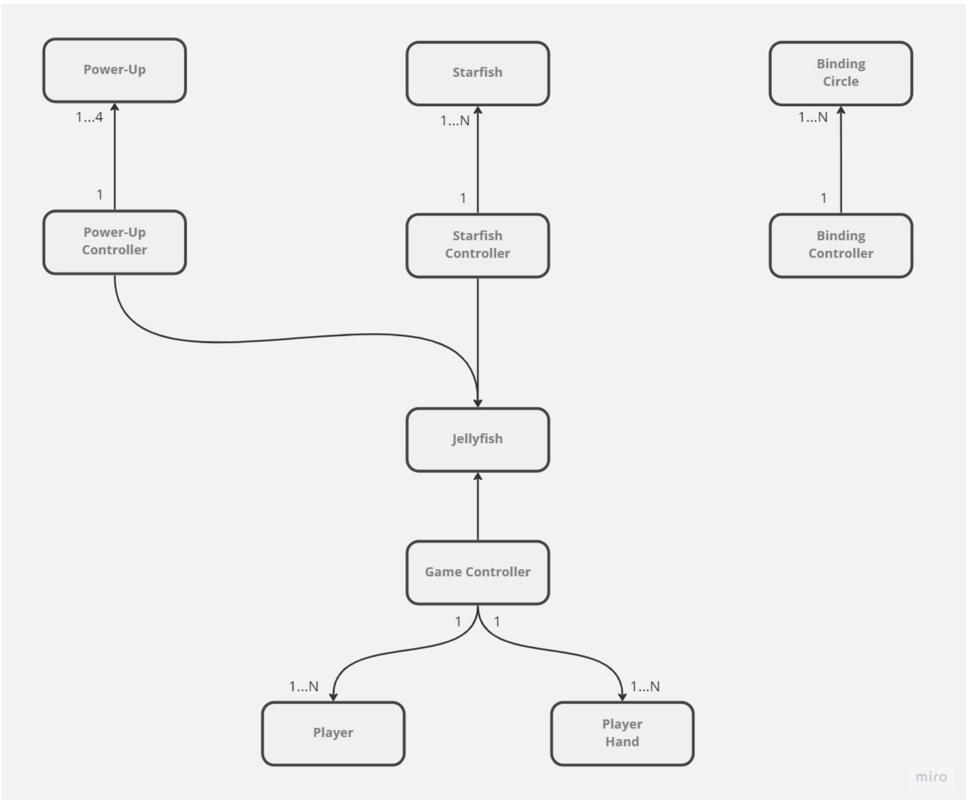


Figure 6.2: UML Model

The Magic Room Adapter is to be considered an external package as it was already present at the time of development of this project. It provides a communication system that can be used to connect and exchange information between multiple devices. It will be further described in the following section, where we will analyze the mechanism behind the communication of the various elements that compose the hardware system. With the following list, we provide a more detailed description of the main components already presented in Figure 6.2:

- **Game Controller:** This is the component that receives and stores the core information about the game (number of players, starting game time, etc...). It is referenced by multiple other components in order to make such info always accessible at run time to the ones that need it.
- **Power-Up Controller:** This component functions as a gateway for the specific instances of each Power-Up to impart changes on the Jellyfish patterns. It receives the imparted modifications and applies them on the Jellyfish's textures.
- **Power-Up:** There are multiple instances of this component. Each one is responsible of monitoring user interaction and communicate with the Power-Up Controller upon being captured. The communication involves specifying the necessary information in order to make the power-up effect take place.
- **Starfish Controller:** This is the component that manages the specific instances of each Starfish GameObject; it spawns Starfishes when needed and monitors their overall behavior. It also provides a gateway for Starfishes to impart changes on the Jellyfish, similarly to what happens with the relation between Power-Up Controller and specific Power-Ups.
- **Starfish:** Similarly to the Power-Up component, Starfishes also have multiple instances, each of which has the role of notifying the Starfish Controller whenever it is captured by a user.
- **Binding Controller:** This component manages the instancing and tracking of Binding Circles. It is also in charge of gathering information from each Binding Circle about the progress made during the binding process. When the binding process is completed, the Binding Controller is in charge of loading the main game scene.
- **Binding Circle:** This component, which can also appear in multiple instances, is used for the realization of the binding process that connects players with Kinect monitored skeletons. Upon being collected, a Binding Circle communicates its information to the Binding Circle Controller, specifying which player has executed the collection.
- **Jellyfish:** This component is the one that gathers all the changes imparted from the various aforementioned controllers. For this reason, it is referenced by other components, all of which can access variables in the Jellyfish system in order to adjust them to the game actions taken by users.
- **Player:** This is the component in charge of representing the users: it both stores

valuable information about the associated player (ID, current emotion, etc...) and it follows the player movement effectively reproducing a player instance within the game world.

- **Player Hand:** Each instance of this component is associated to an instance a Player and is used to track the movement of its user's hand. This component is necessary as Power-Ups are meant to react only when being aligned with the right hand of a player.

6.5. Tablet and Magic Room Communication

As we've already described, the caregiver has two main roles as far as the gameplay is concerned: they have to set up the game session by specifing the required parameters (number of participants and duration of the game session) as well as intervene throughout the session to set players' emotions. In order to do either of these things, the tablet needs to communicate the commands imparted by the caregiver to the Magic Room. This is done through the exchange of json files which contain the instructions that describe what the imparted command is. There are 2 kinds of commands that the Magic Room is expecting to receive from the tablet:

- **Emotion Setting Command:** this command specifies the ID of a player (selected by the caregiver) as well as which emotion needs to be assigned to him/her. The player ID is an int variable with value ranging from 0 to n-1, where represents the number of players. The emotion is instead passed as a string, which will then be mapped to a specific color based on the emotion-color associations showcased in the previous chapter.

- **Time Extension Command:** this command serves as an input for time extension, which is used to add a fixed amount of time to the game session.

The two aforementioned json files are structured in a similar way: they both contain the fields *message* -> *payload* -> *command* and this last field is the one that specifies the type of command associated with the message. Additionally, the "Emotion Setting Command" contains a *body* field within the *payload*, in which the two variables' values are specified. Here are the complete structures of both messages' files:

Additionally, the Magic Room expects a preliminary json file, which we will name "Initial Configuration", to be submitted before the game begins. The information contained in this first exchange is used to set the two parameters that are necessary in order for the game to start, namely the number of participants and the overall session time. The

```
{
    "message": {
        "payload": {
            "command": "game-command",
            "body": {
                "emotion": "angry",
                "playerid": 0
            }
        }
    }
}
```


Figure 6.3: Emotion Setting Command


```
{
    "message": {
        "payload": {
            "command": "add-time"
        }
    }
}
```


Figure 6.4: Time Extension Command

number of participating players is expressed by an int variable, while the session time is expressed by a float. Here the complete structure of the "Initial Configuration" json file:


```
{
    "request": {
        "type": "setConfiguration",
        "payload": {
            "gameConfiguration": {
                "gametime": "180",
                "numofplayers": 2
            },
            "players": [],
            "sessionId": -1
        }
    }
}
```


Figure 6.5: Initial Configuration Message

6.6. Game Engine - Unity

The game has been developed using Unity, which is a royalty free, cross-platform game engine developed by Unity Technologies. Unity provides two different licensing plans depending on the revenue generated by the developers of a given project; in our case, the project has been guided by non-profit reasons, which has lead to us using the personal usage license (more on this in the Ethical Section of the Thesis). We chose to use the version 2022.2.1f1, which was the most up to date at the time of starting the project. Unity can be used to create both 3D and 2D games; as previously mentioned, in our case

the choice landed on a three-dimensional game. Unity also offers the possibility to buy assets from its Asset Store: products found in the store are all user-generated and can be sold at an arbitrary price (some assets are even given out for free). Part of the assets used in our project were downloaded from the Asset Store, meaning they were provided by third parties. C sharp is the primary programming language used to code scripts in Unity, but the engine also offers ways to create/modify objects through the editor and its drag and drop functionalities. As for render pipelines, Unity offers two different options, which are incompatible with each other: High Definition Render Pipeline (HDRP) and Universal Render Pipeline (URP). In our case, we chose to use the URP. HDRP offers more functionalities, but it's also associated with a more expensive computational cost. Given that our project wasn't trying to mimic realist lightning to the degree that HDRP is intended for, we chose to use URP instead, in light of it being more adaptable. It is also worth mentioning that a third option exists when choosing which render pipeline to use: the Built-In render pipeline (Legacy). This option was excluded a-priori from our project as it is the one that offers the least amount of functionalities.
Unity's world consists of two main elements that populate a game and bring the majority of the content together: game objects and components.

- **GameObjects:** Every object inside of a game is a GameObject, from characters and collectible items to lights, cameras and even special effects. However, a GameObject can't do anything on its own; it needs to be given properties before it can become a character, an environment, or a special effect. The addition of said properties is made through the realization of Components, which are then granted to one or more GameObjects.
- **Components:** Components are the functional pieces of every GameObject. They contain properties which can be edited in order to define the behavior of a GameObject. A GameObject can have an unlimited amount of components attached to it and each Component can specify properties of different kinds.

6.6.1. Scenes Breakdown

In Unity the game, scenes represent the environment in which the game is built: they are assets that contain parts or even the entirety of a game or application. An application can have any number of scenes: simple games can be based off one single scene that could contain all the assets relative to that game; while more complex games tend to have an higher scene count in order to break down their content into more simplified parts. In our case, the game is made up by 2 different scenes, with the addition of an introductory scene used to set the communication between the Magic Room and other components:

- **Initial Scene** (Configuration Scene) This scene is used as a set up stage in order to initiate the communication between the Magic Room and tablet. Here the Game Controller receives the information necessary for the game to start, which is then stored and carried across scenes. Said information is expected to be sent by the tablet, which as previously mentioned is managed by the caregiver. Therefore, the caregiver has the role of gathering and setting the two main parameters that the game needs in order to function, those being the overall amount of time that users intend to spend playing and the number of users themselves. It is worth noting that this is a preliminary scene: nothing of relevance is being displayed during this set-up process and the cooperation of players is not yet required.

- **Binding Scene:** This is the other preliminary scene which is laoded in sequence after the Initial Scene has completed the set-up process. The Binding Scene is utilized to complete the binding protocol, which is necessary in order for the game to begin. Upon loading, the Game Controller is in charge of instantiating the correct amount of Player GameObjects (each of which is going to be associated with a different user), which are going to carry an in-game representation of the user. Finally, in this scenes players are asked to follow the previously described binding procedure, which upon being completed is going to load the following and final scene.

- **Main Scene:** This is the scene that contains the core contents of the game. Here the players can experience the game by interacting with the environment and executing the game actions that we have described in previous chapters. Upon loading, this scene starts a countdown based on the timer's value that was previously set up by the caregiver. When said countdown reaches completion, the playing session terminates, resulting in closure of the application.

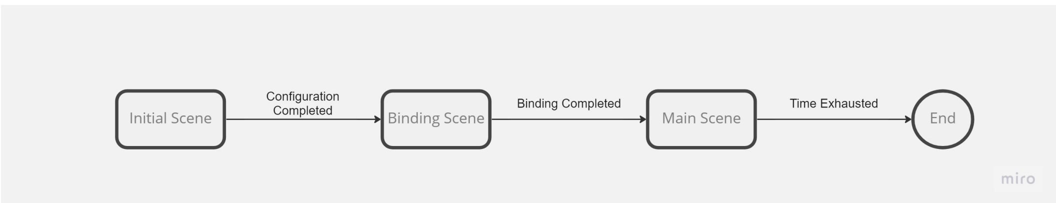


Figure 6.6: Scene Sequence Diagram

6.6.2. Game Camera

In Unity, the camera is the GameObject that portrays the picture to be displayed to the user; in other words it is the device through which the player views the game world. It can be set to two different modes, that largely impact the way the camera captures the surrounding environment: *Orthographic Mode* and *Perspective Mode*.

- **Orthographic Camera:** As the name suggests, this camera mode depicts that captured environment through a process called *Orthographic Projection*. In this mode each pixel rendered by the camera is obtained by tracing a line perpendicular to the camera's orientation which starts from the position of the pixel and extends until it hits a non-transparent object. The result of this approach is that each 3-dimensional object present in the scene is rendered in 2 dimensions instead, eliminating the sense of depth that characterizes the real world. Objects are also rendered with the same scale regardless of their distance from the camera.
- **Perspective Camera:** Contrary to the previous option, this camera mode is instead meant to preserve real world depth and object 3-dimensionality. It is based on a technique called *3D Projection* (or graphical projection) and relies on visual perspective in order to properly transpose 3-dimensional objects into 2D planes. Intuitively, this camera mode is often preferred when working with 3D based environments, contrary to Orthographic Cameras which are instead recommended for 2D settings.

While, as mentioned, both camera modes have a recommended setting in which they should be utilized, as it is often the case with complex systems, multiple factors can actually influence one's final decision on which mode to employ. In our case, the fact that the game is meant to be played by multiple users at the same time and that all of them are experiencing the environment through the same camera has lead us to opt for the orthographic mode when possible, despite this being in collision with the fact that orthographic cameras are often associated with 2D worlds. It would be in fact infeasible to reproduce a perspective view of the world, without first deciding from which point the user is observing; but the fact that multiple users are observing from different places of the room, makes such decision impossible. Additionally, the fact that our game world is populated by both two-dimensional and three-dimensional GameObjects, makes the choice of an orthographic camera even more fit, as it helps merging the two styles into a cohesive result. For this reasons we set the bottom screen camera to orthographic mode. While it would be ideal to do the same for the front screen camera as well, an additional factor has influenced our decision: the screen cameras are meant to portray the in-game world in a way that best conveys the idea that the user is located within said world. In order to achieve such result, we need for the transition from the floor screen to what is displayed on the front screen to feel as seamless as possible: when looking at both screens, the user should feel as if what is displayed in front of them is an extension of what is displayed below. To achieve such effect we need perspective, which is why the frontal camera (the one that portrays the virtual horizon of the scene) is set to Perspective Mode, even if this means contradicting the original points made in favor of orthographic cameras.

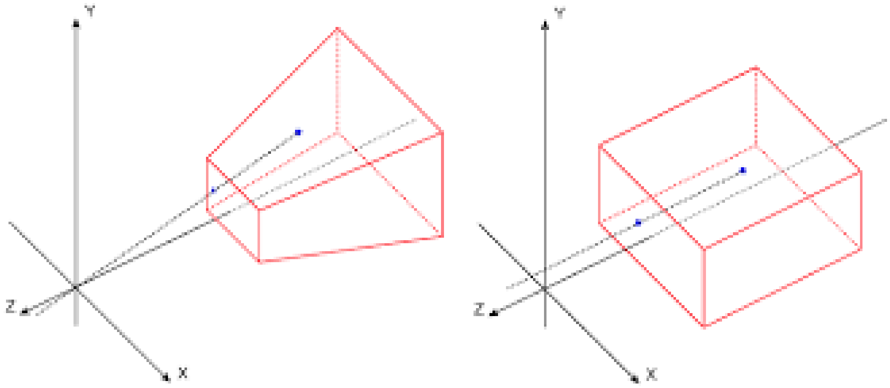


Figure 6.7: Perspective camera (left), Orthographic camera (right)

6.7. Collecting Items

We already discussed how the main game action that a player can take is that of capturing starfishes and power-ups. Both these game actions rely on an identical system that keeps track of which items are being interacted with and who is the player that's producing the interaction. Said system is based on the forwarding of Raycasts by each object that can be interacted with, starfishes and power-ups alike.

In Unity, a Raycast is a straight line that is generated from a given point and extends along a specified direction. Its goal is to determine whether there are relevant GameObjects found along the path, in which case they provide a reference to said GameObjects, meaning that the entity which generated the Raycast would then be able to access relevant information about the encountered GameObjects. As mentioned, starfishes and power-ups both send Raycasts with the intention of investigating whether a player is lining up in their path; if that is the case, the item would know that a player is interacting with it and the process of capturing is then initiated. At this point, if the Raycast keeps hitting the player for a long enough time, the item is captured and behaves accordingly based on whether it is a starfish or a power-up.

The information that interactive entities are on the lookout for when throwing a Raycast is the following:

- **Hit Result:** First and foremost, the entity is interested in knowing whether a player is lining up in front of itself. In order to not mistake other GameObjects as possible hits, a layermask is set, which implies that only player associated GameObjects can be hit.
- **Interaction Length:** In order to keep track of how much progress has been made by the player in capturing the entity, a float variable stores the amount of time that has passed since the first Raycast hit. This variable is updated at every frame and is eventually reset to 0 in case of a Raycast miss.
- **Player ID:** The entity is also interested in knowing which specific player is interacting with it. Upon completing the capturing process, only the player who made the capture has to be impacted by its results.

The aforementioned Raycast system is continuously active, meaning that each interactive entity is forwarding a Raycast during every frame throughout the duration of the scene. If at any frame the Raycast misses a hit, the progress tracked thus far is reset and the capturing process is interrupted.

6.8. Technical Art

Part of the work that went into the realization of this software has come in the form of producing game elements and adjusting their appearance in order to fit the style, role and meaning that were envisioned for them. Almost all the items that eventually made it to the final prototype of the game have been created by our team, mainly through the tools provided by Unity (particle system, shader graph, etc...), but also with the help of third party programs (such as Blender). In this section we describe how the main GameObjects were designed and realized from a technical art point of view, as well as the major tools that were employed in order to achieve the desired results.

Here is a brief description of the two main tools that Unity offers to adjust and complement the appearance of GameObjects:

- **Shader Graph:** Shader Graph is a node-based system that enables the creation of networks which regulate the shaders inside a game. Shaders allow to manipulate the way pixels are rendered by the camera, and are utilized to modify the way an object "looks". They represent the basis of material that GameObjects are composed by and dictate the rules that said materials will follow once the object is inserted within the game world. As a result, Shaders create the foundation for determining most aspects of a GameObject's appearance: they can determine the way an entity's surface interacts with light, its color and transparency, as well as a vast array of visual effects that can be directly portrayed on top of the object's surface itself.

- **Particle System:** the Particle System is a GameObject that contains a collection of small images (particles) which create a "fuzzy" object when viewed together. Particles can be manipulated through the adjustment of various parameters: rendered image, color, velocity, direction and many more. This allows the Particle System to be a versatile tool that can be used to create all sorts of visual effects; in our project it has mainly been employed as a complementary instrument used to reinforce visual feedback effects generated by interactive items.

6.8.1. Sand Seabed

The sand seabed, which is arguably the most visually impactful piece present on the floor screen of the Magic Room, has been realized with the help of Shader Graph. Our shader uses a combination of two major effects in order to define the final realization of this GameObject's appearence: *Sand Texture* and *Caustics Effects*.

- **Sand Texture:** This part of the seabed's appearance is obtained by combining multiple sub-effects that are independent from each other and cooperate to create the final semi-realist look that we wanted for the sand. None of these effects is strictly necessary in order to obtain a texture that reminds the look of actual sand, but they're all employed to eventually bring together a cohesive result:
  - *Ripple Normals:* One of the most characteristic aspects of sand is the ripple shape that its surface takes as a result of the forces that it is usually subjected to. In our shader, this surface shape was obtained by the modification of the seabed GameObject's normal map. The normal changes were made through the use of a ripple normal texture that was downloaded from a third party website.
  - *Granular Normals:* When looking at real life sand, it often appears to our eyes as if it as a granular surface instead of being smooth: indeed, this happens because sand is composed by multiple tiny grains that can have different shape and reflect light independently from each other. Given how this is another effect that impacts sand's look through the modification of its shape, it was also executed by modifying the GameObject's normal map. In order to reproduce

the granular look of sand, we used a technique called bumped mapping: it involves changing the local orientation of the surface normals in order to create the look of a non-smooth surface. In this case, we needed a new normal map that would be composed by a seemingly endless count of points, each with its on orientation relative to the object's surface. Intuitively, we need some degree of randomness in order to achieve such an effect; however, simply assigning a random rotation to each point would yield unrealistic results, as there would be points within the map with a inwards normal, which is never possible for a non-convex object. So we used a simple noise to generate the initial map that represents the rotation of each point, but then re-mapped it such that the values of each point's rotation would always be positive (meaning each point is rotated in an outwards looking direction). Finally, the obtained granular normal map needs to be "blended" with the ripple map obtained in the previous step: there are many ways to unify normal maps into a single texture, in this case we chose to simply add the values of both maps together.

  – *Diffuse Light:* This is the last effect that we implemented; it consists on modifying the way the seabed GameObject reflects light based on its surface's overall orientation. To be more specific, real-world objects that have the capacity to reflect light are impacted by their rotation relative to the user when doing so. If a sand object is creating exactly a 90° angle between the spectator and a light source, then its reflection is going to be maximized. On a similar logic, as the angle between the spectator and the light source shrinks, the reflection also becomes less shiny, as a result of the fact that less light is being reflected in the spectator's direction. We realized such effect by simply implementing in Shader Graph the phenomenon that was just described: for each point on the seabed GameObject's surface, we calculate the angle that it creates between the camera (spectator's point of view) and the light source (we used the main light source of the scene, disregarding the other light sources that might exist throughout the game session). The value found in this step is then used to decide how shiny that given point of the surface should be: its emission is regulated based on how big the angle is, relative to an interval that ranges between 0-90 degrees.

- **Caustics Effect:** A caustic is an envelope of light rays that are curved or projected on a surface through reflection and/or refraction. Given how this effect is often featured in real life water, it is one of the main elements that need to be reproduced in order to recreate a semi-realistic representation of water in video-games. While it is technically possible to recreate a realistic simulation of this effect; reproducing caustic ripples with an high fidelity is often really demanding from a computational point of view, as it would involve the simulation of an incredibly high number of light rays. For this reason, we chose to base our effect around the use of a caustic ripple texture that is modified appropriately in order to sell the idea of moving light rays. The first relevant aspect of this texture is that it is tileable, meaning two instances of said texture could be placed next to each other and there would be any obvious seams as a result. This is key as the light rays need to be applied to the entire body of the seabed, but they also need to be scaled and moved independently, which most likely implies there's going to be the need of using multiple textures instead of a single big one. Intuitively, step one of creating the caustic ripple effect involved tiling the original texture in order to cover the entirety of the seabed object's surface. At this point the only thing left to do is animate the texture(s) in order to simulate the movement of light rays. This is done through a technique called multi-sampling: the same texture is sampled more than one (twice in this case) and each sample is moved independently in its own direction. Finally, both texture samples are blended into a single, final one which is applied to the seabed GameObject. The blending process is executed by calculating, for each point within the final texture, the minimum value among the two respective points in the original independent samples. The final product is a believable representation of caustic ripples without the need of performing an actual simulation of the light rays' movement.

These two effects then need to be combined into a final texture that is finally applied on the seabed GameObject. As previously mentioned, there are multiple ways we could use to combine two textures; once again we chose to simply add them together, creating an overlay between the two effects.

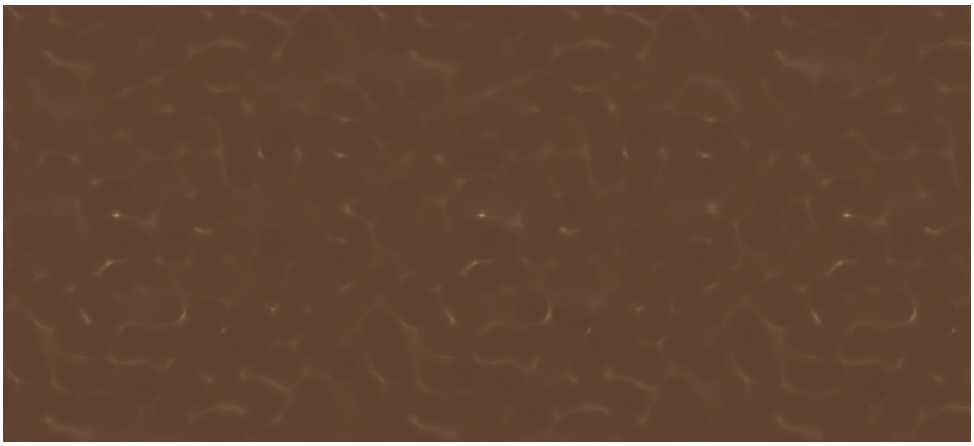
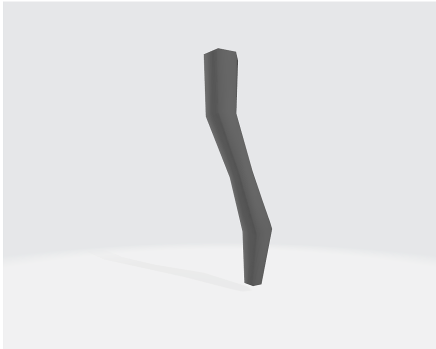


Figure 6.8: Final result of the sand seabed once both effects are active

6.8.2. Jellyfish

The Jellyfish is arguably the main GameObject of the scene, as it is both the one that ties together all players' emotions as well as the item that occupies the most screen space (in the front screen). This GameObject has been realized with the help of a combination of tools: Blender and Shader Graph. Our designer modeled the basic shape of the jellyfish cup (Figure -) in Blender, which was then complemented by in-game generated tentacles (Figure -). Each tentacle is created at run time as a separate GameObject, which allows us to manipulate it independently from the other parts of the Jellyfish. As a result, the displayed Jellyfish is actually a combination of multiple independent GameObjects, all grouped together under a single parent which can be moved and rotated in order to impart coordinated movements and rotations to each specific child GameObject. There are three effects that are worth discussing relative to the implementation of the jellyfish: *Animation*, *Movement* and *Texture*. The animation of the jellyfish involves only manipulating the vertex displacement of the tentacles, without impacting the cup's shape. This is done through a script that manages each tentacle's vertices and changes their position following a recursive formula. The movement of the jellyfish is instead executed by changing the transform (position and rotation) of the parent GameObject, which as a result moves around both the tentacles and cup. The movement formula involves confining the parent GameObject within a virtual sphere and randomly selecting a direction for it to move towards. Upon reaching the edge of the sphere, the jellyfish changes direction and starts moving back towards the center of the sphere, never leaving screen sight a result. Lastly, the creation of the final texture that is assigned to the jellyfish has been done in Shader Graph: the jellyfish is assigned a baseline color which never changes throughout the session; however, that is complemented by a pattern texture which is a combination of all the patterns owned by the players. For each player, at all times in the game the jellyfish retrieves their current pattern, as well as their emotion (and associated color). It then combines all the patterns and colors into a single final texture, by simply adding each player's separate texture into a single one.

(a) Jellyfish 3D model



(b) Tentacle 3D model

6.8.3. Starfish - Model and Shader

Starfishes are based on a simple .FBX 3D model (Figure -) that gives the foundation of the GameObject's rendered shape, which has been realized in Blender by the designer of our team. The model, which is then been imported onto Unity, is complemented by a Shader that has the role of adjusting the appearance of the Starfish's surface. Each Starfish is associated with one or more patterns, which are displayed on top of its surface using the aforementioned Shader. Patterns depicted on top of a given Starfish are randomly selected before instantiating the GameObject itself. The Starfish's shader contains two texture input parameters, each of which is going to be potentially filled with a texture file associated with a given pattern. As we've already mentioned in previous sections, Starishes normally carry a single pattern, meaning that one of the input textures is often left empty. However, in order to have the possibility of creating more interesting results, whenever the game features only two players, Starfishes are instead spawned with a combination of two patterns depicted on their surface.

Moreover, the Shader of a Starfish contains also a base color input which determines the overall coloring of the object's surface in the areas that aren't covered by the patterns. Said parameter is set by default to a fixed color (pale red), which represents the appearance of the Starfish's surface upon being instantiated. However, when the starfish is collected by a player, this parameter is updated to match the user's current associated emotion-color pairing; which also implies that the starfish is going to update its surface color in case subsequent emotion changes in its user are noticed.

The pattern's input texture(s) is combined with the basic color of the GameObject's surface by simply overriding the areas of the Starfish that are covered by the pattern itself. The following figure provides a visual summary of the Shader's syntax:

Figure 6.9: .FBX model of Starfishes

6.8.4. Starfish Feedback Effect

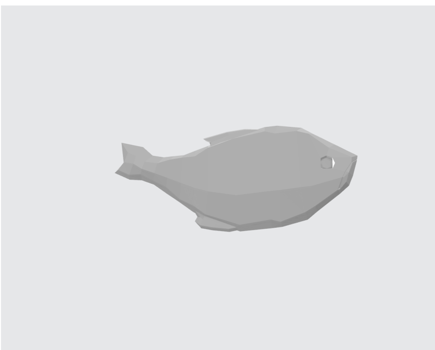
As we've already discussed in previous sections, starfish GameObjects can be interacted with by the user by standing on top of them and eventually collecting them. In order to give a feedback to the user, which reinforces the idea that they're making progress in capturing the starfish, we implemented two simple visual effects:

- **Increased Emission:** Starfishes carry a pattern that remains white colored for as long as they don't belong to a player. Upon standing on top of a starfish, a player starts the collecting process which is accompanied with a color change of the starfish pattern, which becomes increasingly shinier as the collecting process progresses. The shiny look is achieved by not only increasing the pattern's emission, but also progressively changing its color from white to yellow.
- **Particle System:** As previously mentioned, if the player stays on top of a starfish long enough, they are eventually going to collect it. When this happens, the starfish releases a group of particles that are sprinkled as a symbol of success. The particles all originate from the starfish's center of mass and move outwards, each in its own independent direction. Additionally, they are released with a relatively high starting speed, which quickly starts decreasing until they stop moving. The particles' transparency is inversely proportional to their speed, meaning that they start to vanish upon being released until they finally disappear upon reaching a null speed. To complement this visual feedback, the starfish also plays a quick sound effect upon being collected as a way to reinforce the idea that the process has been completed successfully.

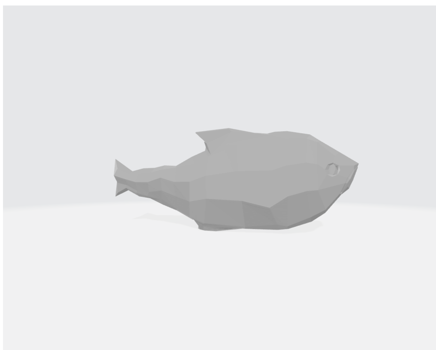
As described in previous sections, the Starfish is going to start following the player around upon being collected. In order to differentiate collected starfishes from the other ones, we decided to complement the already described change of surface color with an additional particle system effect. Said effect is based on the generation of particles that create a trail line whenever the starfish moves in towards a different location. The generated particles are spawned in the position just visited by the starfish and carry an initial momentum which makes them move with decreasing velocity towards the direction that the starfish has followed, effectively tracing back the same path. Additionally, the particles' transparency is tied to their life time by a directly proportional formula: the particle is instantiated with full opacity and progressively becomes more transparent as time passes, until it disappears and is finally removed.

6.8.5. Power-Up - Model and Shader

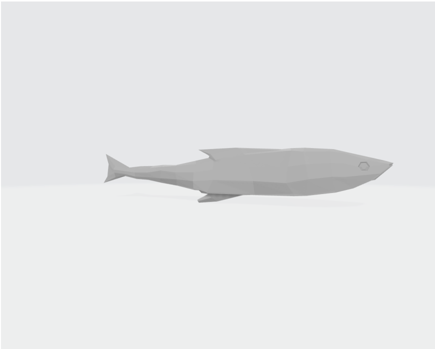
Power-Ups are also based on .FBX 3D models (Figures 6.10a, 6.10b, 6.10c, 6.10d) that represent the GameObject's basic shape. In this case, the models where imported from a free-for-use assets package downloaded form Unity's Asset Store. There are 4 different 3D models, each of which is assigned to a different Power-Up and all of them represent a slight variation of a fish. Unlike Starfishes, Power-Ups don't need to adjust their color or overall appearance throughout the playing session, meaning that there has not been the need to develop a dedicated Shader. The Power-Ups color is simply set in the material window and is assigned a default value (pale range) which is shared by all 4 instances of Power-Ups.



(a) Power-Up (1) 3D model



(b) Power-Up (2) 3D model



(c) Power-Up (3) 3D model

(d) Power-Up (4) 3D model

6.8.6. Power-Up Feedback Effect

Similarly to starfishes, a user can interact with power-ups by holding their hand in front of the GameObject. Given how the collecting process for power-ups also requires to keep track of how much time has passed since the user started collecting it, we decided to add a similar feedback effect to the one already showcased for starfishes. Power-Up items are composed of two separate GameObjects: the fish icon, which is different for each power-up and serves the simple purpose of distinguishing power-ups from each other, and a capturing quad, which is the item that keeps track of the progress made by the user in collecting the power-up. The latter is initially invisible, but starts appearing once the user places their hand in front of the power-up. It consists of a glowing circle that surrounds the fish icon and is only partially displayed: specifically it is horizontally cut and only the bottom part is displayed. The height of the cut is determined by how much time has passed since the user started capturing the power-up, meaning the circle starts from being completely invisible and gets progressively bigger as the user's hand stands in front of the power-up, until it is fully visible, in which case it means that the collecting process is complete. Once circle is finished rendering completely, the power-up releases a particle system effect that is identical to the one described in the starfish section. Upon completion, the power-up also plays a small sound effect used to reinforce and better communicate the idea of success to the user.

Finally, when the collecting process of is completed, the power-up resets its appearance to the initial position: the released particles slowly disappear and the luminous circle goes back to being invisible, once again representing a 0 percent capturing state.

7 | Evaluation Methods

7.1. Explora - Study Context

In a world based on a society that constantly requires people to be flexible and produce innovative solutions to ever changing problems, developing creativity at a young age can be a urging necessity.

While extensive research has been conducted on the topic of enhancing children creativity with the support of Multi-Sensory Environment [64], none of it has been specifically conducted with the intention of determining whether social interactions could have a correlation with creativity.

Before introducing our study's design, it is necessary to note how investigating the creative processes behind one's mind is a rather complex task, especially in the case of subjects with ASD. As of now, the topic of creativity is relatively under-explored which implies the absence of a standardized testing method. For this reason, our study's main goal has been to focus firstly on whether the experience has been perceived as pleasant by the participants.

Recently i3Lab has conducted an explorative study with the intent of investigating the impact of group dynamics on individual creativity within a Multi-Sensory Environment setting. More specifically, said study was aimed at exploring the area of creative ideas sparked from an individual's mind, when being part of a group activity. In order to conduct such investigation, i3Lab developed "Explora": a multisensory experience in which two children can interact together, coordinate, and explore an idyllic digital world to discover its secrets. Explora is also based on the Magic Room, which provides the users with a smart space that can be interacted with and presents the players with an experience centered around the themes of discovery and exploration. In Explora, two children play simultaneously and can experience together the immersive system that they are part of: the goal for the users is to discover as much as they can about the world in which the experience takes place, which is regulated by mechanisms that players don't know of at the time of starting the session.

Given the numerous similarities shared between Explora and our project, we decided to use our study as a way to gather and analyze additional data on topics of creativity, emotion and user connection.

7.2. Problem Statement and Objectives

As of now, to the best of our knowledge, no scientific studies have examined group dynamics' impact on individuals' creativity in the setting of a Multi-Sensory Environment. So, in order to lay down a solid foundation for the analysis of children's emotions, we decided to conduct a study centered around the exploration of social interactions among individuals who take part in group activities. In particular, the focal points of our investigation will be: how children collaborate when facing a cooperative artistic process, how they develop social interactions, and how these influence their creative process.

More specifically, we will analyze the following research questions:

- Does a correlation between social interaction and creativity exist?
- Does a correlation between creative thinking and creative action exist?
- Does a correlation between creativity and engagement exist?

7.3. Participants and Ethical Considerations

Participants who took part in this study were 3 male, neuro-typical children with ages comprised between 6 and 8 years old. All children involved volunteered to take part in the experiment without solicitation or coercion of any kind. All participants, being minors, had to have an adult caretaker sign two consent forms (one for the consent on taking part in the activity, one for the consent on being video and audio recorded) in order to participate. Participating children as well as their parents (who assisted at the experiments) retained the right to interrupt the session at any time during the experiment. Both the analyzed data that was derived from videos, as well as the data taken from the questionnaires has been gathered and kept anonymous throughout its analysis and publishing on this thesis. Additionally, said data has not been utilized for any purpose beyond the conduction of this study.

7.4. Materials and Procedures

This study involves the analysis of play sessions conducted by groups of two children each. The experiment was conducted in the Magic Room installed at i3Lab, Politecnico di Milano. All sessions where audio and video recorded in order to be analyzed by us through the examination of notable behavioral signals, which were kept track of according to the table 7.4. Said table has been developed using the Explora behavior classification table and adapting it to our study following the unique game mechanical elements that are featured in Oceania, but aren't shared with Explora. In the left column are listed the macro categories of relevant behaviors that children could exhibit during the play test, while the right column lists all the instances of said behaviors. Signals listed in table 7.4 were kept track of "on the spot" during the execution of the experiment, but as mentioned above are also meant to be further analyzed by examining the video recordings through the execution of a Video Content Analysis.

Each group of two children has taken part in a 10 minutes long play session, which has been introduced by a vocal explanation of what the game is about prior to beginning the actual experience. Each participant has taken part in the experiment only once, in order to minimize the impact that having familiarity with the environment could have on the subject. Finally, each play session has been monitored by a supervisor, in order to provide assistance to the participants in case of need.

The following table lists all the relevant behavioral signals that children could send throughout the playing session. Said signals are focused on social interaction, dynamic engagement, and changing the sequence of social actions between individuals or pairs in a Multi-Sensory Environment. They represent the behavioral conducts that we were in the lookout for when examining the recorded videos of play test runs. Children may present those behaviors through verbal communication, body interaction, body gestures, and peer-to-peer communication.

Variables	Behavioral Signal
Engagement	Facial expression of joy
	Verbal expression of joy
	Facial expression of surprise
	Verbal expression of interest
Bored/Tired	Verbal expression of frustration
	Verbal expression of tiredness
	Agitated body motions
	Loss of attention
	Loss of interest
Creative Action	Stand on a starfish
	Capture a power-up
Creative Thinking	Talk about patterns
	Talk about colors changing
	Discuss ways to impact Jellyfish's appearance
	Talk about ideas
Social Communication	Eye contact with other user
	Closeness to other user
	Verbal communication with other user
Need for Intervention	Adult verbal intervention
	Adult physical intervention
	Adult technical intervention
	Verbal expression of incomprehension or confusion

Additionally, each participant is then asked to answer a questionnaire in order to gather their perspective about taking part in the experiment. The proposed questionnaire (Appendix A) contains 3 separate sections that are aimed at investigating different areas of the user's experience. Each section is based on items directly imported from other existing questionnaires: *User Engagement Scale* (Short Form), *System Usability Scale*, *Net Promoter Score*. In order to make said items more understandable for the target users, questions taken from the 3 aforementioned questionnaires have been slightly reworked: firstly they have been translated in Italian and, after having done so, some items have been simplified in the way their syntax is constructed. Lastly, it is necessary to mention how all three parts of the questionnaire are structured independently from the participant they are given to, meaning each user was presented with the same items.

7.4.1. Part 1 - User Engagement Scale (UES-SF)

The first part of this questionnaire features all 12 items from the User Engagement Scale - Short Form [61] questionnaire, which is a widespread feedback analysis tool utilized in various digital domains in order to measure user engagement. The employed 12 items can be divided into 4 macro categories, each of which is meant to measure a more specific part, referred to as "factor", of the user's experience: focused attention (FA), perceived usability (PU), aesthetic appeal (AE) and a 4th factor (RW) derived from combined items taken from the UES - Long Form. Each of the aforementioned categories contains 3 items that are rated by the participant according to an agreement scale that ranges between values 1-5: the value 1 represents total disagreement with the statement posed by the item, while 5 represents complete agreement.

7.4.2. Part 2 - System Usability Scale (SUS)

The second part of the questionnaire is composed by some questions extracted from the System Usability Scale form [11], which provides a reliable tool for measuring usability of a given system. The original SUS form is made up by 10 total items with five response options for participants, ranked from "Strongly disagree" to "Strongly agree", relative to the statement posed by its associated item. Part of the 10 total items have been omitted from our own questionnaire in order to make it easily understandable to our target users; this has lead to minor adjustments in calculating the overall usability score, which will be explained in more detail in the next chapter.

7.4.3. Part 3 - Net Promoter Score (NPS)

The Net Promoter Score (NPS) [52], which makes up the third and final part of our questionnaire, is a tool aimed at measuring the overall satisfaction of users. It consists of a simple survey question which divides customers in different categories based on their answers in order to produce final data which can be analyzed for benchmarking:

8 | Results and Discussion

8.1. Data Analysis and Results - Questionnaires

8.1.1. Part 1 - User Engagement Scale (UES-SF)

The analysis of the first part of the questionnaire has been conducted accordingly to the standard guidelines provided by O'Brien et al. in their article [61], which provides a practical guide towards measuring user engagement.

In order to conduct such analysis, we firstly retrieved each data value and converted it in a positive scale. To do so, items 1, 4, 5, 6 have been reverse coded in order for their values metric to be in line with the remaining items. Then, for each participant, we calculated both the final score (representative of their overall engagement) as well a score for each of the 4 items categories:

- **Category Score:** for each of the 4 item categories, its associated score can be calculated by finding the median of its questions scores.
- **Overall Engagement Score:** the final engagement score can instead be calculated by computing the median of all 12 items values.

In the following figure, we present the results of the aforementioned analysis:

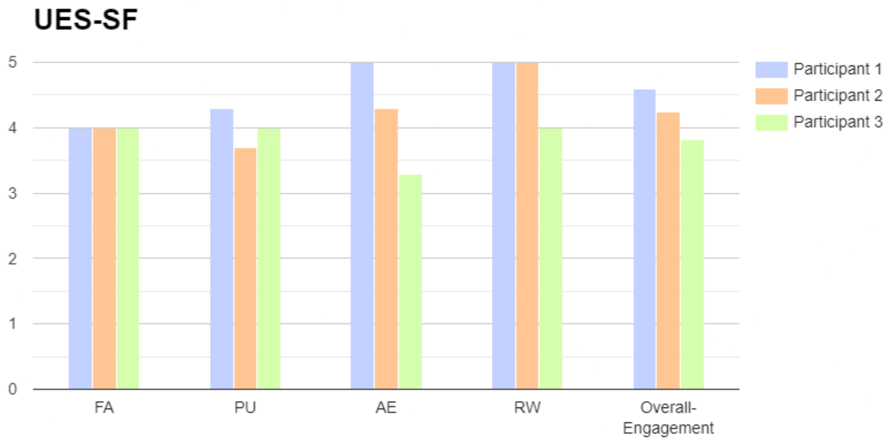


Figure 8.1: UES-SF data chart

8.1.2. Part 2 - System Usability Scale (SUS)

As explained in the System Usability Scale guide [11], items featured in this second part of the questionnaire can be divided into two groups: *positive contributors* and *negative contributors*.

- **Positive Items:** Items 2, 3 and 5 are part of this group. The scores associated to these items' responses are calculated according to the following formula:

$$SC = SP - 1$$

  Where the scale position (SP) indicates the value assigned to the statement by the user and the score contribution (SC) represents the value that the given response provides to the total usability score. A higher value in the participant's response is indicator of better usability for items that belong to this category.

- **Negative Items:** Items 1, 4 and 6 are part of this group. These items were reverse coded according to the following formula:

$$SC = 5 - SP$$

Each item's score contribution ranges from 0 to 4 and is calculated independently according to the two formulas described above. Once each individual item's score has been calculated, the overall usability score can be calculated by converting the scale from 0-4 to 0-10 and summing all items' values. Additionally, as mentioned in the previous chapter, considering how some items from the original SUS form were not included in our questionnaire, results need to be adjusted relative to the amount of total items featured in this instance. For this reason, the total achievable score for our questionnaire is 60 as opposed to the original 100.

The following figures represent the results of each participant who's taken part in the experiment, from which we can deduce the median final score among all three participants, which is: $FS_m = 41$.

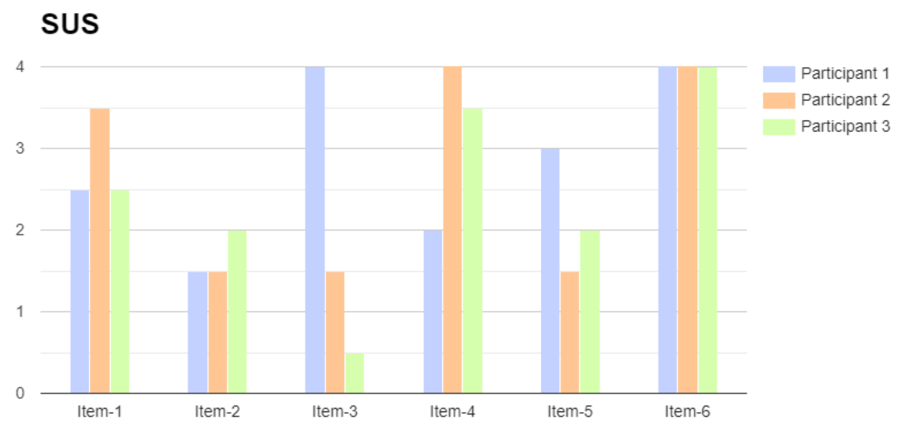


Figure 8.2: SUS data chart

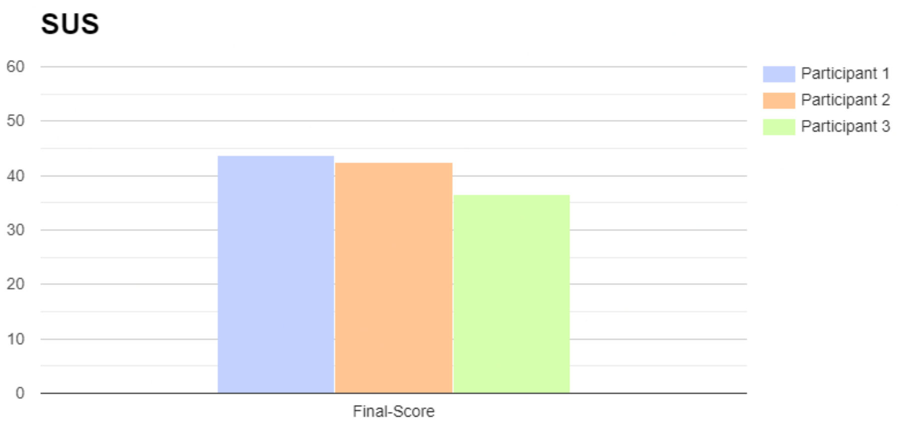


Figure 8.3: SUS final score chart

8.1.3. Part 3 - Net Promoter Score (NPS)

The posed question of this third part contains possible responses that range within a 1 to 10 scale. Based on the value assigned by their response, each participant can be ranked into one of the following customer categories:

- **Promoters:** respond with a score of 9 or 10 and are typically loyal and enthusiastic customers.
- **Passives:** respond with a score of 7 or 8. They are satisfied with your service/product but not happy enough to be considered promoters.
- **Detractors:** respond with a score of 0 to 6. These are unhappy customers who are unlikely to interact with us again from a business perspective, and may even discourage others from doing so.

The following figure provides a representation of each participant's evaluation:

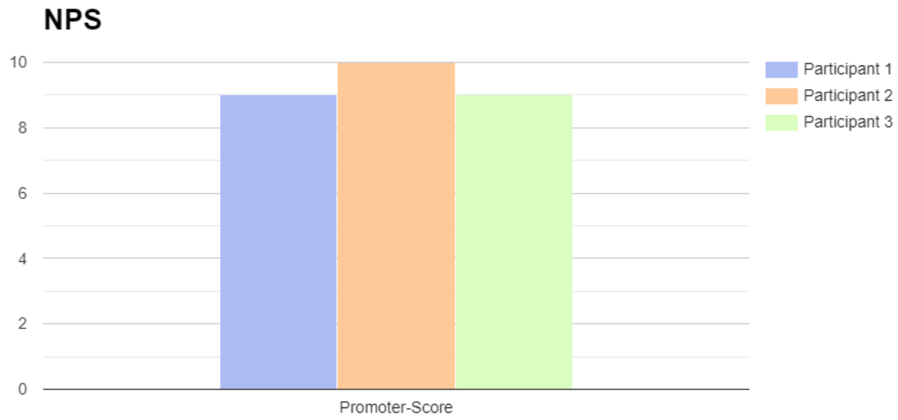


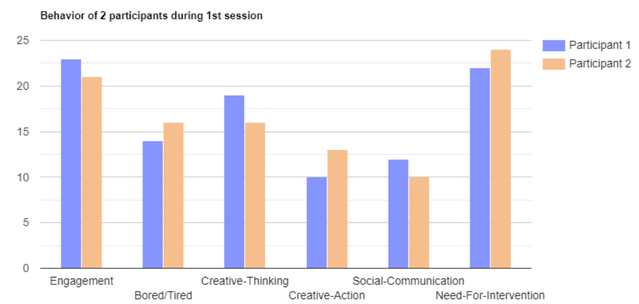
Figure 8.4: NPS data chart

As the graph shows, all three participants would recommend trying our application out with a value of 9 or greater, meaning they can all be considered Promoters.

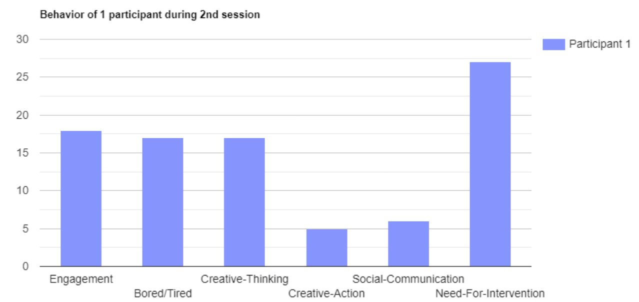
8.2. Data Analysis and Results - Video Recordings

As mentioned in the previous chapter, all sessions where monitored by at least one supervisor which, among other things, had the role keeping track of the behavioral signals previously listed. The analysis of this data has started with the assignment of each signal to a macro-category (already described in table 7.4) in order to conduct a quantitative analysis. The resulting data has then been classified into separate sessions, each of which produced a sequence of reported occurrences among the previously introduced six behavioral categories: involvement, bored/tired, creative action, creative thinking, social communication, and need for intervention.

The following figure represents the data collected in two separate sessions where a total of 3 children participated in. The first session features 2 of the 3 aforementioned participants, while the other session has been run with the remaining participant being paired with an adult in order to still make them play as a group. Together, the two charts represent for each participant the percentage of their exhibited behavioral signals relative to the total amount of signals displayed throughout the playing session. In the two figures, the blu-bars values represent the percentages associated with the first participant of the session, while the orange-bars values are associated with the second participant.



(a) 1st Session (2 Children Participants)

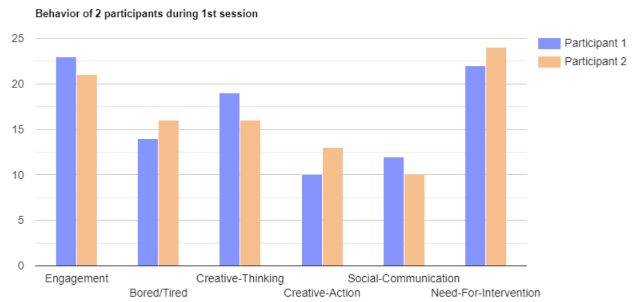


(b) 2nd Session (1 Child Participant)

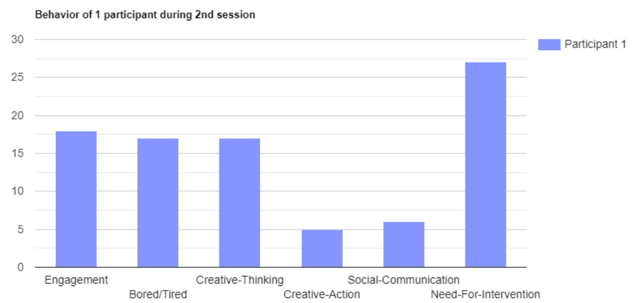
The presented data has then been converted into an Excel file in order to measure possible correlations between creative-related behaviors and other displayed actions (such as social interactions and engagement), which will be discussed in the following section.

8.3. Discussion

8.3.1. Results Analysis



(c) 1st Session (2 Children Participants)



(d) 2nd Session (1 Child Participant)

Starting from the results shown in Figures 8.5c and 8.5d, we tried to derive whether there exists a statistically significant correlation between the various categories of behaviors exhibited by participants. We started out by mapping all values previously showed into an Excel file and by creating two additional broader behavior categories: *Creativity* -which contains the sum of Creative Thinking and Creative Actions behaviors- and *Social Interaction* - which contains all socially related behaviors-. We then continued by calculating Pearson's Correlation Coefficient and p-value for every pairing of behavior categories that was believed to be meaningful in possibly answering the research questions previously posed. The following table contains all such pairs, as well as the derived values for Pearson's Correlation Coefficient:

Category Pairings	Pearson Coefficient, p-value
Creative Action - Creative Thinking	$r = -0,188982237$ $p = 0,094178373$
Social Interaction - Creative Action	$r = -0,989743319$ $p = 0,007609451$
Social Interaction - Creative Thinking	$r = 0,327326835$ $p = 0,001437338$
Social Interaction - Creativity	$r = -0,866025404$ $p = 0,022184304$
Engagement - Creative Action	$r = 0,70463404$ $p = 0,020949118$
Engagement - Creative Thinking	$r = 0,56362148$ $p = 0,109129194$
Engagement - Creativity	$r = 0,917662935$ $p = 0,035098719$

Before diving into the analysis of the results shown above it is necessary to note that the rather limited sample size of this study prevents us from making any definitive claim about the correlation between the investigated variables.

Correlation between Social Interaction and Creativity

The shown data seems to point out that Social Interaction and Creativity indeed have a non-statistically significant ($p = 0,022184304$) correlation. More specifically, we found a strongly negative correlation between these two categories of behavior ($r = -0,866025404$). Mathematically speaking, a negative Pearson Correlation Coefficient implies that the two examined variables share a linear and inversely proportional link. However, we shouldn't stop at such a broad interpretation of this finding: we can instead use the two components of creativity -namely Creative Actions and Creative Thinking- to further explore how creativity relates to social interaction in this context. Social interaction and creative actions seem to have an even stronger negative correlation ($r = -0,989743319$), this suggests that of the two components of creativity, the one that is most impacted by interacting with other children is the "active" component of this category. More intuitively, we can interpret this statement as the fact that being socially involved in group activities can hinder one's impulse to take on actively creative behaviors. The correlation value between social interaction and creative thinking is instead rather surprising considering the relationship that the former category has with creativity: their Pearson Correlation Coefficient is positive ($r = 0,327326835$). This could mean that social interactions can have contrasting repercussions on creativity as a whole: they tend to *enhance* creative thinking instead of discouraging it, as it instead happens with creative actions. We can speculate on the possible reasons behind these results, but can't provide any reasonable proof for why this is the case. A possible explanation for such phenomenon is that getting socially involved with other participants directly impairs one's ability to take other actions: when communicating with others, children can have a tendency to focus on the communication alone, pausing other tasks completely. However, social interactions seem to be either independent from creative thinking or even a light catalyst for it. This could be explained with the fact that social communication can still leave participants with a way to explore ideas while the interactions take place.

Correlation between Creative Thinking and Creative Action

Concerning the question of a possible correlation between creative action and creative thinking (the two components of this experiment's creativity category), data shows that there isn't any statistically significant ($p = 0,094178373$) correlation between the two variables ($r = -0,188982237$). A mathematical interpretation of a negative correlation coefficient (however mild), points out how the two variables' behaviors follow inversely proportional, linear trends. However, in this case the absolute value of the found correlation coefficient is too small to suggest a significant correlation between creative thinking and creative action.

It is worth to point out that other studies have found a more pronounced correlation between the two variables. For example, Scibinetti et al. [77] discuss how, according to their findings, there are common factors between the processes that regulate the production of both creative thoughts and creative actions, possibly leading to conflicts between the two behaviors. The differences between our study's finding regarding this research question and other studies could potentially be attributed to low sample size.

Creative thinking is at the base of any creative process, as it lays the foundation for essential competencies that children need to have in order to make decisions. A mild negative correlation between creative thinking and creative action can be explained as creative movement could indirectly interfere with creative thinking as both behaviors share commonalities in their responsible processes.

Correlation between Engagement and Creativity

Finally, concerning the correlation between engagement and creativity, data shows a non-statistically significant ($p = 0,035098719$) positive correlation between the two variables

($r = 0,917662935$. Mathematically, this implies that the growth of either of these variables is complemented by the linear growth of the other variable. Intuitively, we can interpret this finding as engagement being a catalyst for creativity: it seems that a user being actively interested in the experience can foster creative behavior by boosting interest in searching for solutions to the existing problems. Once again, it is worth to dive into a more in-depth analysis of creativity in order to understand how its individual components each relate to engagement. According to the showcased data, creative actions maintain a rather high correlation coefficient with engagement ($r = 0,70463404$: this could suggest that creative actions are the portion of creativity that are most impacted by the user being engaged in the experience. Intuitively, we can speculate that this is the case as high levels of engagement often translate into a more impulsive behavior, especially in a really young demographic (such as the one featured in this study). More specifically, engagement seems to foster user's active commitment to making progress in the experience, which means physical actions are more likely than passive creative actions to be impacted. As far as correlation between engagement and creative thinking is concerned, the found correlation coefficient still retains a positive value ($r = 0,56362148$, but is diminished in intensity relative to the other creative component. This could be explained as creative thinking stimulation is still likely to benefit from user's engagement, but less so relatively to how creative actions are impacted. Once again, we could justify this with the intuitive idea that engagement is often associated with more impulsive and physical actions as a response. Finally, it is worth to point out how engagement has been a relatively highly represented behavior category; this could be explained by the fact that all participants were completely foreign to multi-sensory environments prior to taking part in this experiment. We can speculate that the novelty element carried by a new environment can be the cause behind the user feeling engaged in an activity never tried before. Additionally, integrating data from the UES-SF section of the questionnaire, we can see how aesthetic appeal is one of the highest rated components: this element has likely played an active role in making children more interested in interacting with the environment, thus fostering engagement signals.

8.4. Limitations

Our study presents several limitations that are worth mentioning before executing an analysis of results. Firstly, the sample size of this study is rather limited: this can lead to results that are not representative of general trends, but are instead skewed in unrealistc fashion by variance. For this reason, the shown results should only be considered preliminary; meanwhile in order to make progress on this front, we will continue on recruiting more participants and, in doing so, expand the sample size. Another important aspect of this study is the impossibility to determine whether results were impacted (either directly or indirectly) by the fact that all participants were completely new to multi-sensory environments. The novelty associated with taking part in an experiment that focuses by a large degree on a tool that participants haven't seen or used before implies that results can be impacted by children's ability and willingness to adapt to such novelty. Lastly, given how some technical issues have arisen during some testing sessions, children have needed more guidance than expected in order to be able to properly utilize the application. In order to still keep track of their behavioral signals relative to the voice "Need for Intervention", we voluntarily decided to not take note of behaviors belonging to such category that resulted from technical impairments.

As stated above, results provided should be taken as provisionary, but we still feel as they can provide useful insight in answering questions that are still left unsolved in the worlds of multi-sensory environments and social relationships.

9 | Conclusions and Future Work

9.1. Conclusion

With this thesis, we presented our multi-sensory environment based application, Oceania, as well as the exploratory study that MSEs can have on children's creativity and social interactions.

Oceania has been developed in order to feature an engaging and immersive experience within multi-sensory environments: it presents itself as a game-based activity meant to be experienced through a full-body interaction system, typical of Magika's activities. Its main aim is to provide young users with a medium to express their creativity as well as socialize with their peers. This software also features a way to visually keep track of emotion connections between users, which as described throughout this work, has been as focal point of both the development of the application, as well as the conduction of the exploratory study.

The development process of Oceania started with an introduction and analysis of the background that concerns the fields of multi-sensory environments, autism spectrum disorder and emotions. This has been presented through the examination of the state of the art where we described the progress made in recent years by other projects and studies, with regards to the aforementioned fields of interested. Starting from such foundation, we then initialized the development of Oceania itself, which has been thoroughly explained in both its design phase -realized in conjunction with our team's designer as well as other experts' guidance- and its development stage.

The main contribution of this thesis is that of highlighting the potential that MSEs have with regards to helping children in areas such as introspection and social dynamics. The development of this software, which has been realized following a design-implementation process, has then been complemented with an exploratory study with the aim of shedding light on some key research questions still left unanswered in the world of multi-sensory environments.

Despite some technical limitations, we believe our research can still lay the foundation on answering questions that could possibly bridge the gap between social interactions and creativity. We gathered data concerning the social and creative behavioral signals that users displayed while play-testing Oceania, and finally conducted an investigation in order to determine whether certain categories of such behaviors could have a statistically significant correlation. The study has also been complemented with the submission and subsequent analysis of feedback questionnaires, that users have completed in order to provide a more detailed understanding of their perceived engagement and overall system's usability.

9.2. Future Work

While there are many directions that can be explored in order to progress on the work that was done with this project and paper, here we want to suggest some of the most notable inclusions that this work could benefit from in light of future contributions.

Firstly, we believe that improving the study's data is a priority in order to make progress in answering the research questions that were discussed in previous chapters: as described in the apposite section, our study's sample size has been contained due to technical limitations; integrating additional data would provide further confidence to the results found with our research. Additionally, a possible route to follow on such improvements could be that of conducting one or more studies more focused on directly exploring issues and themes more related to non-neurotypical children. In order to lay a solid foundation for such work, we decided to conduct a study that could retain usefulness in broader fields, but a more specific approach should be considered as the next step.

Another area that could be investigated in the aim of improving the proposed work is the automation of data collection: the study conducted by our team has been live monitored by one or more supervisors during each session. Finding a way to gather data without influencing participants can possibly represent an additional leap in results advancements. One way to favor such approach is that of creating an automated log system, which would be in charge of keeping track of notable variables without the necessity of human intervention. It is important to note that automated logs can't completely supply the data needed to conduct a study such as the one presented in this work, hence it would be important to employ a complementary way for supervisors to gather data without interfering with participants (a one-way mirror can be a possible solution to this issue).

As far as the application itself is concerned, the possibilities to improve on it should be mostly seeked in the aesthetic component: aesthetic appeal has proven to be a major component of user's engagement, especially in Oceania's case, which leverages immersiveness as one of its main drawing points. Collaborating with experts from other artistic fields, such as music and visual art, could help the application with regards to being even more attractive than it currently is.

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A | Appendix A - Questionnaires

The following questionnaires (written in English and Italian respectively) contain questions that were posed to the participants after having taken place in our experiment:

Magic Room Questionario

User Engagement Scale

UES-SF

Mi sentivo spaesato durante l'esperienza (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

Il tempo è volato mentre usavo l'applicazione (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

Ero immerso nell'esperienza (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

Mi sono sentito frustrato mentre usavo l'applicazione (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

Ho avuto l'impressione che l'applicazione fosse difficile da usare (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

Usare l'applicazione mi ha richiesto molte energie (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

L'applicazione è stata attraente (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

Ho trovato l'applicazione interessante a livello visivo (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

L'applicazione è risultata piacevole ai sensi (1 = per niente d'accordo, 5 = totalmente d'accordo)

Figure A.1

○ ○ ○ ○ ○

Ne è valsa la pena provare questa applicazione (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

L'esperienza è stata gratificante (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

Mi sono sentito interessato all'esperienza (1 = per niente d'accordo, 5 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5

System Usability Scale

SUS

Ho trovato che l'applicazione fosse eccessivamente complessa (1 = per niente d'accordo, 10 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9 ○10

Ho trovato che l'applicazione fosse facile da utilizzare (1 = per niente d'accordo, 10 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9 ○10

Penso che la maggior parte delle persone riuscirebbe ad imparare velocemente come usare l'applicazione (1 = per niente d'accordo, 10 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9 ○10

Ho trovato che l'applicazione fosse eccessivamente difficile da usare (1 = per niente d'accordo, 10 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9 ○10

Mi sono sentito sicuro di ciò che stessi facendo mentre usavo l'applicazione (1 = per niente d'accordo, 10 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9 ○10

Ho dovuto imparare molte cose prima di poter usare l'applicazione (1 = per niente d'accordo, 10 = totalmente d'accordo)

○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9 ○10

Figure A.2

Net Promoter Score

NPS

Su una scala da 1 a 10, quanto consiglieresti questa applicazione ai tuoi conoscenti?

○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9 ○10

Figure A.3

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